AD-A205 982

ARI Research Note 89-11

Factors Influencing Army Maintenance

Debra C. Evans and J. Thomas Roth
Applied Science Associates, Inc.

for

Contracting Officer's Representative
John F. Hayes

Manned Systems Group
John F. Hayes, Chief

Systems Research Laboratory
Robin L. Keesee, Director

DTIC
ELECTE
MAR 2 8 1989
S D
D

January 1989

United States Army
Research Institute for the Behavioral and Social Sciences

Approved for the public release; distribution is unlimited

89 3 28 087

U.S. ARMY RESEARCH INSTITUTE FOR THE BEHAVIORAL AND SOCIAL SCIENCES

A Field Operating Agency Under the Jurisdiction of the Deputy Chief of Staff for Personnel

EDGAR M. JOHNSON
Technical Director

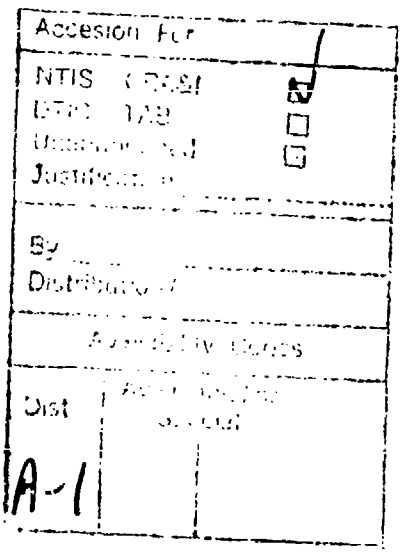
JON W. BLADES
COL, IN
Commanding

Research accomplished under contract
for the Department of the Army

Applied Science Associates, Inc.

Technical review by

Richard P. Kern
Uldi Shvern
William F. Stratton



NOTICES

DISTRIBUTION: This report has been cleared for release to the Defense Technical Information Center (DTIC) to comply with regulatory requirements. It has been given no primary distribution other than to DTIC and will be available only through DTIC or the National Technical Informational Service (NTIS).



FINAL DISPOSITION: This report may be destroyed when it is no longer needed. Please do not return it to the U.S. Army Research Institute for the Behavioral and Social Sciences.

NOTE: The views, opinions, and findings in this report are those of the author(s) and should not to be construed as an official Department of the Army position, policy, or decision, unless so designated by other authorized documents.

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS --
2a. SECURITY CLASSIFICATION AUTHORITY --	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE --	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) --	5 MONITORING ORGANIZATION REPORT NUMBER(S) ARI Research Note 89-11
6a. NAME OF PERFORMING ORGANIZATION Applied Science Associates, Inc 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION U.S. Army Research Institute for the Behavioral and Social Sciences
6c. ADDRESS (City, State, and ZIP Code) P.O. Box 1072 Butler, PA 16003	7b. ADDRESS (City, State, and ZIP Code) 5001 Eisenhower Avenue Alexandria, VA 22333-5600
8a. NAME OF FUNDING/SPONSORING ORGANIZATION Same as 7a. 8b. OFFICE SYMBOL (If applicable) PERI-SM	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER Contract OPM-87-9034, Work Order 534-003
8c. ADDRESS (City, State, and ZIP Code) Same as 7b.	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. 2.63.00 / PROJECT NO. A793 / TASK NO. 1.2.7 / WORK UNIT ACCESSION NO. 1.2.7.C.1
11. TITLE (Include Security Classification) Factors Influencing Army Maintenance	
12. PERSONAL AUTHOR(S) Evans, Debra C., and Roth, J. Thomas	
13a. TYPE OF REPORT Final 13b TIME COVERED FROM 87/11 TO 88/06	14. DATE OF REPORT (Year, Month, Day) 1989, January 15. PAGE COUNT 89
16. SUPPLEMENTARY NOTATION John F. Hayes, Contracting Officer's Representative	

17. COSATI CODES		
FIELD	GROUP	SUB-GROUP

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
MANPRINT, Early estimation, Personnel, Maintenance, Modeling, Training, Logistics, Manpower, System acquisition,

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Factors and variables that influence maintenance for systems and related manpower, personnel, and training (MPT) characteristics were identified in a review of literature. The results of the literature review were used to develop several conceptual models to support early investigation of the potential effects on maintenance MPT characteristics of decisions early in the acquisition process. The models developed include a maintenance demand factors model that identifies the factors that potentially influence system maintenance burden; a maintenance driver factors model that relates the joint, propagated consequences of early acquisition decisions on later system characteristics important to maintenance; a maintenance process model that identifies actions and decisions generic to all levels and types of maintenance; and two acquisition influence models, one for the Accelerated System Acquisition Process (ASAP) and one for Non-Development Item (NDI) acquisitions, that relate the variables in the maintenance demand factors model to events in the two acquisition processes that can influence related characteristics of the fielded systems.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL John F. Hayes	22b. TELEPHONE (Include Area Code) (202) 274-8883 22c. OFFICE SYMBOL PERI-SM

DD Form 1473, JUN 86 *Previous editions are obsolete.* SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED

FOREWORD

Maintenance is a critical function in sustaining combat readiness and mission capability. The importance of an effective and efficient maintenance capability for fielded systems cannot be overestimated. Early decisions in the acquisition process can have profound influences on the level and nature of the maintenance demand of fielded systems. Relatively little is known about the consequences of decisions made during the acquisition process on the performance capability and related manpower, personnel, and training (MPT) demands of maintenance functions. Also, the tools available for research into such issues are not fully adequate for projecting the consequences of early decisions on the characteristics of fielded systems.

As part of its continuing support to the MANPRINT program, the U.S. Army Research Institute for the Behavioral and Social Sciences (ARI) is developing methods to explore the effects of decisions early in the acquisition process on maintenance and related MPT characteristics of systems. The research that is the topic of this report represents a first step toward the development and application of such methods.

EXECUTIVE SUMMARY

Requirement:

The primary objective of this effort was to identify variables and factors that affect the performance of Army maintenance, and to develop conceptual models of the relationships among these variables. A second objective was to prioritize research topics among the factors and variables identified.

Procedure:

A detailed review of literature on maintenance policy, practices, and performance was conducted. The results of this review were used to develop several conceptual models of the influences of various factors on maintenance demand and performance. Based on the conceptual models, a set of domains of maintenance influencing variables were prioritized for future research attention.

Findings:

Five conceptual models concerning maintenance were developed. They are a maintenance demand factors model that identifies the factors that potentially influence system maintenance burden; a maintenance driver factors model that relates the joint, propagated consequences of early acquisition decisions on later system characteristics important to maintenance; a maintenance process model generic to all levels and types of maintenance; and two acquisition influence models, one for the Accelerated System Acquisition Process (ASAP) and one for Non-Development Item (NDI) acquisitions, that relate the variables in the demand factors model to events in the acquisition processes that can influence characteristics of fielded systems. Research approaches, based on modeling of the maintenance process and case studies, were defined to guide future work in this area.

Utilization of Findings:

The models and research approaches developed in this effort provide a foundation for the future development of tools to assess the effects of decisions early in the acquisition process on the maintenance function and related MPT characteristics of fielded systems. Development and use of models of maintenance processes to explore the consequences of decision alternatives on fielded systems is a preferred approach for future research.

CONTENTS

	Page
INTRODUCTION	1
Background	1
Relationships Between Models	2
Format of Report	4
METHODOLOGY	5
Review of the Literature	5
MAINTENANCE DRIVER FACTORS MODEL	9
Driver Factors	9
Driven Factors	14
MAINTENANCE DEMANDS MODEL	17
Model Dimensions	17
Factors	20
DIRECTIONS FOR FUTURE RESEARCH	41
Suggested Research Method	44
REFERENCES	49
ANNOTATED BIBLIOGRAPHY	53
APPENDIX A. ACRONYM LIST	A-1
B. GLOSSARY	B-1
C. MAINTENANCE PROCESS MODEL	C-1

LIST OF TABLES

Table 1. Maintenance demands model	18
2. Definition and evaluation of research approaches	42

Page

LIST OF FIGURES

Figure 1. Driver factors model C-12

C-1. Maintenance process model C-13

FACTORS INFLUENCING ARMY MAINTENANCE

INTRODUCTION

Background

As the complexity, sophistication, and capabilities of military systems increase, so does the need for a strong maintenance capability for these systems. Given expectations for numbers of systems available for future fielding, the maintenance component must be made as effective and efficient as possible in order to guarantee that each materiel system is maximally ready. In order to assure the performance of the maintenance function, valid estimates of the maintenance burden for the materiel system must be made during the early stages of system development.

Although the importance of the maintenance component and the need to estimate its burden have been recognized by the U.S. Army for a long time, there have been few efforts to clarify or define the factors that comprise the elements of the maintenance burden. The importance given to these factors and factor interactions and how they are controlled over the life-cycle of a system, will impact the performance of system maintenance. If the factors impacting or constraining maintenance, their interactions, and their potential levels of impact are established, the information may be used to perform maintenance burden estimation. Methods for using such information must indicate the factors to be addressed, and the means for doing so, as part of the development of manpower, personnel, and training (MPT) requirements for the materiel system.

The U.S. Army Research Institute for the Behavioral and Social Sciences (ARI) supports the MANPRINT program by conducting research and development to provide methods to evaluate and project MPT requirements for new and existing systems. One aspect of this support is developing techniques to assess the implications of factors that influence the maintenance function on maintenance-related MPT characteristics of systems. The purpose of this effort was to develop a conceptual foundation for developing such techniques.

This project had three major thrusts. The first project goal was to develop a model or set of models that describe the derivation and application of the maintenance concept for materiel systems. These models were to delineate factors and factor interactions that are potentially pertinent for the optimization of the performance of maintenance which in turn could produce reductions in maintenance burden. Four types of models were developed:

1. Driver Factors Model that presents the factors of importance for the estimation of maintenance burden during system acquisition and their relationships.

2. Maintenance Demands Model that portrays the factors impacting both the planned and the real maintenance burdens.

3. Maintenance Process Model that presents the steps that occur when a maintenance action is initiated.

4. Two event models presenting the steps that occur during the acquisition process (as portrayed by the Army Streamlined Acquisition Process and the Non-Development Item Acquisition Process) and the factors from the driver and maintenance demands models that pertain to each event.

The second goal of this effort was to evaluate existing logistic, maintenance, and MPT modeling approaches for their capability to support early estimation of MPT characteristics related to maintenance. The objective was to select modeling approaches to be evaluated, and then assess the ability of each selected approach to accommodate estimation related to the variables in the maintenance demands model in this report.

The third goal was to develop a list of prioritized research areas derived from the factors and processes illustrated by the models developed during the course of this project. The prioritization of research areas was based on their potential for reducing the maintenance burden at relatively low cost.

This report contains the models developed to fulfill the first and third goals of this project. A second report (Roth, 1988a) contains the results of the second goal of this project.

Relationships Between Models

The models presented in this report (driver factors model, demands model, and process model) each represents a different view or context for the maintenance function. As such, the models are not orthogonal with regard to the issues they address. In fact, the ways in which they overlap can be used as a means for their integration.

In the following paragraphs, the linkages between the models will be described. This description is general in nature, because as the reader examines the models, the relationships will become more self evident. A brief section at the conclusion of this report also summarizes these relationships.

The demands model presents the factors that impact the maintenance function, when these factors play a role, and the controllability of these factors. The model presents factors, identified from a review of the literature, that may occur at different points in the life cycle of the system, beginning with the acquisition process and estimation of maintenance burden and MPT requirements, continuing through use of the system and the resulting actual maintenance burden. This model does not present any causal links between factors, only an identification of the factors.

The maintenance driver factors model focuses on the factors that impact maintenance burden and MPT estimations during the acquisition process. Thus, the driver factors model addresses many of the same issues as the demands model identified as acquisition factors. However, the factors that appear in the driver factors model are not a proper subset of those contained within the demands model; the driver factors represent expansions of acquisition factors appearing in the demands model. The driver factors model also presents the propagational relationships between the identified factors.

The third model, the maintenance process model (located in Appendix C) presents the steps that occur when a materiel system requires maintenance. These steps themselves are not reflected in any of the other models. However, the basic maintenance process model has been supplemented with information from the demands model. Each step in the process model has been examined to determine the factors from the demands model having a potential impact on the step. Combining these models in this way is an effective means for identifying where in the maintenance process one could expect to see the results of modifications to individual demands factors.

The final two models, the Army Streamlined Acquisition Process and the NDI Acquisition Process, are process models detailing the steps that occur during the acquisition process and the documentary output of those steps. These two models present the time lines for system acquisition. As models of the acquisition process, the ASAP and the NDI acquisition processes overlap with each other substantially. Also, some of the outputs of the events described in these models occur as factors within the driver factors model. These models are on file as ARI working papers.

The two acquisition models do not overlap with the maintenance process model, however. Additionally, they do not share any information with the demands model except as mediated by the expanded demand factors appearing in the driver factors model. However, the events that occur during system acquisition have been examined in relation to the factors presented in the demands and driver factors models. This examination was performed to determine: 1) which acquisition events potentially impact the maintenance function, and 2) which maintenance factors (or issues) are addressed during each event. The ASAP and the NDI acquisition process models have been supplemented with this information concerning the demand and driver factors relevant to each acquisition event. In this way, the reader may be able to

identify the acquisition events important to the development of the maintenance function and the estimation of maintenance burden.

Format of Report

This report contains 9 text sections in addition to this introduction. These sections are as follows:

1. The methodology used to perform this project;
2. The driver factors model;
3. The demands model;
4. A discussion of directions for future research;
5. Reference list;
6. Annotated Bibliography of relevant research;
7. Appendix A - Acronym list;
8. Appendix B - Glossary of terms;
9. Appendix C - Maintenance process model;

METHODOLOGY

Review of the Literature

The initial step in the development of the models presented in this report was an extensive review of the literature. Literature focusing on any or all of the branches of the armed forces was examined, but the primary focus was on Army-specific information. The literature reviewed for this project and cited in the text is listed in the References section. Information was gathered and reviewed that pertained to the following topics:

1. problems in the performance of maintenance;

2. models of maintenance, including constraint, event-series, and process models; and

3. determination of maintenance burden and driver factors.

Literature on the first of these topics was examined in order to identify factors whose impact on the maintenance component has been recognized after all MPT decisions for a system have been made. The post hoc recognition of problems can be seen as a strong indicator of the factors that impact the actual maintenance burden and which may be controllable prior to system deployment. The literature examined consisted primarily of two types of research studies. One sort of study, typified by Harz (1981), reports the results of questioning large numbers of Subject Matter Experts (SMEs) involved in the maintenance process. The second type of report focuses on data available from existing databases to determine if system design requirements and system support design requirements have been met after target systems have been fielded (e.g., Fredrickson, et al., 1987).

Models of maintenance were examined for guidance in the selection of both potential components and formats for the models under development. The process models and event series models that were reviewed provided a foundation for the maintenance process and event models presented here. Literature representing the third model type, consisting of constraint models, was examined for congruence with the factors identified from research studies. Brief descriptions of the reviewed models appear in the Annotated Bibliography.

Materials on the way in which maintenance requirements are determined were used to guide the derivation of the driver factors model.

Development of Driver Factors Model

This model was developed through a review of the literature on Integrated Logistic Support (ILS) requirements and MPT decision procedures, including the AMC/TRADOC Pamphlet 70-2 (Materiel Acquisition Handbook). The outcome of this review is a distillation of the factors which drive the determination of requirements for the maintenance component of a materiel system, and related influences on systems' MPT characteristics.

Development of Demands Model

Five steps occurred in the development of the demands model for maintenance. First, as with all of the models presented here, pertinent literature was reviewed. The review included literature on maintenance constraint models (Campbell and Kane, 1986) and on identified maintenance problems (e.g., Kokenes, 1987; Harz, 1981).

The second step was the identification of demand factors that affect the actual maintenance burden. Factors mentioned in the literature as having a major impact on maintenance were tentatively identified as components to include in the model.

After factors were selected, a format for the model was chosen. The format was required to allow grouping or ordering of the factors by their relative importance. The selected format is based on that of a maintenance demands model developed for the Air Force (Campbell and Kane, 1986).

The fourth step in developing the demands model was to place the factors into the selected format. This was done with guidance supplied by the documentation reviewed.

The last step in the development of the demands model was to tentatively identify interactions between the factors. Again the literature from which the factors were initially drawn was the primary source for identifying interactions.

Development of Process Model

The process model has proceeded through three stages in its development to this point. First, the literature was examined as discussed in the previous section. This literature included reports by Chenzoff (1985) and Clements (1984). The literature supplied information as to levels of specificity that maintenance process models encompass, as well as the contents of these models.

The literature served as a starting point for the development of the model. After the literature was reviewed, the second stage of the development process was to make a decision as to the level of detail

appropriate for the model. This decision was based on the level of detail presented in similar models and the amount of detail that could be supported by either personal knowledge of the maintenance process or by the literature.

The contents of the model and its logic were determined. Again, both reviewed literature and personal knowledge were used to accomplish this task. Finally, this model was integrated with the factors presented in the demands model.

Development of Event Models

Two event models were developed, one each for the ASAP and the NDI acquisition processes. The models are based on information from AMC/TRADOC Pamphlet 70-2.

Steps for each process were identified and listed. Each step in a process was then examined to determine the following information:

1. agency with major responsibility;
2. input information to the step;
3. output of the step; and
4. the factors from the driver factors and the demands models applicable to the step.

Validation of Models

The models were validated through discussion with two types of SMEs: 1) personnel involved in the determination of maintenance burden during system acquisition, and 2) personnel with experience performing maintenance within a military context.

MAINTENANCE DRIVER FACTORS MODEL

This model describes the determinants of the maintenance burden for a system, and the interrelationships between various factors and processes that ultimately drive the maintenance characteristics of a system. The model also attempts to identify the propagated impacts of maintenance burden as they influence issues of central importance in the MANPRINT process: manpower, personnel, training, and organization. The purpose of this model is to provide a framework for evaluating the contributions and impacts of various factors and attributes of system design and development that influence the maintenance process and maintenance requirement.

This model is intended to be compatible with, and partly descriptive of, the system acquisition process as exemplified by the Life Cycle Systems Management Model (LCSMM; DA PAM 11-25) and the ASAP. Certain elements in the model are related to acquisition documentation produced during the acquisition process (e.g., Organizational and Operational [O&O] Concept, Required Operational Capability [ROC], Basis of Issue Plan [BOIP], Qualitative and Quantitative Personnel Requirements Information [QQPRI], and Tables of Organization and Equipment [TOE]). Reference to these documents pertains only to elements and influences within the model itself; the total content of the documents is much greater than solely the parts related to the model.

The driver factors model is shown graphically in Figure 1 (the first foldout page at the back of this volume). In general, driver factors' influence propagates from left to right across Figure 1. The processes and elements shown at the far left of Figure 1 are the source drivers of the maintenance demand for a system and the system's ultimate MANPRINT and other characteristics. Immediately to the right of these source driver factors are elements considered to be intermediate drivers that influence the driven characteristics. Elements and processes appearing further to the right in Figure 1 are the driven characteristics associated with the maintenance function.

The remainder of this section describes the elements and relationships included in the driver factors model.

Driver Factors

Four elements have been identified which are currently thought of as the source drivers of the maintenance demand for a system, and therefore for MPT characteristics of the maintenance function. Two of these are directly related to the system acquisition process, one to

system design, and the fourth to the characteristics of the potential manpower tool.

Acquisition Process "Requirement and Constraint" Drivers

The two drivers related to the acquisition process are:

1. The O&O concept for a system drives some of the characteristics of the maintenance function. For example, the number of systems to be placed in a unit of a given type determines to a certain extent the gross maintenance manpower required to perform maintenance within that organization, subordinate organizations, and organizations higher in the chain of command. In general, the fewer systems of a given type that are present in an organization, the less the gross maintenance burden associated with that system type will be, other things being equal.

   The O&O concept also may establish goals and impose constraints that influence some of the characteristics of the maintenance subsystem. If, for example, there is a desire to minimize the absolute number of unique Military Occupational Specialties (MOSs) associated with maintenance of a system, this may increase skill requirements for members of particular MOSs. This could hypothetically constrain the characteristics of personnel that are selected into MOSs that maintain the system.

   In many cases, characteristics of the potential manpower pool available to support a system may influence goals and constraints in the O&O concept. These can include the likely number of personnel available in the manpower pool or population, force structure limitations, and the distribution of general and specific aptitudes among population members. This is illustrated in Figure 1 by the flowline leading from "Manpower Pool Characteristics" to the "O&O Concept" block.

   Three key elements of the O&O concept that have significant influence on the maintenance characteristics of a system are the maintenance strategy and maintenance concept identified in the O&O concept, and the operational tempo, that identifies projected system use rates. These are discussed below.

2. The performance requirements and constraints on system characteristics embodied in the ROC for a system are major drivers of maintenance demand and MPT factors for any system. The specific performance requirements for a system determine the range of design choices which are reasonable and feasible to implement in developing a new system. For

example, a requirement for a cannon system that has certain range, rate of fire, and safety characteristics constrains the system designer's choices among available technology alternatives. The technology and engineering choices made in the design process in turn influence system MPT demand characteristics.

Specific constraints embodied in the ROC also place limits on system design choices. For example, if a limitation on the uniqueness of the battlefield optical and thermal signatures of a system is imposed, then at least some restrictions are made on the form factor and thermal emission characteristics of the system design.

While it is not yet common practice to constrain the resultant MANPRINT characteristics of a system designed to fulfill a particular operational capability, providing such constraints can influence the MPT demands of system design.

Design Initiatives to Facilitate Maintenance

The third source driver factor relates to the design initiatives and principles used in the design of the materiel system. These include the following:

1. Human factors engineering (HFE)--the extent to which appropriate design choices are made to minimize the difficulty of operator and maintainer tasks and simplify training for operation and maintenance of a system.

2. Maintainability design--the extent to which design choices are made that make the system easy to maintain, from the viewpoints of servicing, repair, and fault isolation. This includes such considerations as "design for discard," which support a particular maintenance concept and strategy for a system.

3. Accessibility design--the extent to which design choices are made which make it simple and straightforward to access components of the system to perform maintenance. This includes in particular minimizing the number of unrelated component removals required to access each component of a system.

4. Testability design--the extent to which provisions are made during design to enable efficient testing and fault isolation of a system.

Using these design principles can influence the extent to which maintenance is required for a system, and therefore reduce to some

extent the manpower and other resource demands of required maintenance. Use of these principles can also reduce the difficulty of performing various aspects of maintenance. This can sometimes be accompanied by a reduction in the overall level of skill required to accomplish maintenance functions. Obviously, such factors as battle damage cannot be eliminated in the design process, but fault isolation and repair, as well as routine and preventive maintenance, can be significantly affected by design initiatives.

Manpower Pool Characteristics

Another, more or less independent, driver factor is the characteristics of the manpower pool from which personnel that perform maintenance are drawn. Two important attributes of the manpower pool are numbers of people available and the distribution of aptitudes across personnel who are potential maintainers. The aptitudes of the people available to perform the maintenance function interact with the characteristics of maintenance tasks to determine such factors as:

1. training requirements;
2. some required characteristics of test and diagnostic equipment;
3. required characteristics of technical documentation; and
4. the time required to perform each maintenance task.

Also, the absolute size of the manpower pool is a direct constraint on how much maintenance (in terms of maintenance manhours) is allowable as a consequence of system design.

Ideally, as Figure 1 illustrates, the characteristics of the potential manpower pool should influence both of the "requirements and constraints" driver factors—the O&O concept and the ROC. As expressed in these documents, system operational concepts and requirements should not demand numbers of personnel or aptitudes that are not likely to be available in the manpower pool. Manpower pool characteristics (e.g., the Target Audience Description [TAD], described in the System MANPRINT Management Plan [SMMP]) should also influence system design directly.

Intermediate Drivers

The driver factors above interact to determine or specify several factors at a more concrete level. These factors are also major drivers with respect to the maintenance function and many associated considerations, including organization design, manpower requirements, training nee s, personnel selection and classification (and MOSs), logistical support requirements, and personnel subsystem functions. The intermediate drivers are, as their label suggests, both driven by the source

drivers and, in turn, drive system design and maintenance characteristics, as well as MPT demand. Three major intermediate driver factors have been identified. These are discussed below.

System Design. The first three source driver factors above, operating jointly, determine many of the characteristics of any system design. The system design itself is one of the primary drivers of the characteristics of the maintenance function. System design drives the maintenance function through determining the tasks that are required to maintain systems at required levels of availability, the frequency with which each task must be performed, and the personnel knowledges, skills, and abilities (KSAs) required to perform each task.

Maintenance Concept. A second important driver factor is the maintenance concept selected for the system. A maintenance concept determines how many levels of maintenance there will be in a maintenance system, and the general rules by which maintenance tasks are allocated across the various levels of maintenance. There is significant variability in the maintenance concepts for different types of systems.

A common maintenance concept for Army systems (see AR 750-1) is a three-level maintenance system (unit maintenance; intermediate maintenance, composed of intermediate direct support [IDS] and intermediate general support [IGS]; and depot). Other maintenance concepts include two-level (unit and depot) systems. No attempt is made to explain specific maintenance concepts here. For the interested reader, a comprehensive discussion of maintenance concepts is found in Nauta (1983).

A key consideration about the maintenance concept for a system is that the maintenance strategy determines the types of tasks that are to be performed at each level of maintenance, and the subsystems, assemblies, and components on which each task is performed. Thus, repairs performed at the unit level may be limited to removal and replacement of "black box" or major assembly elements of the system, which are fault-isolated and repaired at higher levels of maintenance. The distribution of maintenance tasks across levels of maintenance under a particular maintenance concept has a significant influence on the distribution of manpower across the levels of maintenance. This, in turn, can ultimately affect organizational structure, MOS distributions, equipment placement and basis of issue policy, personnel skill requirements and distribution, and manpower requirements.

Jointly, system design and the selected maintenance concept drive many of the characteristics of a maintenance function, either directly or indirectly.

Maintenance Strategy. The maintenance strategy for a system identifies the overall approach to be used for maintaining a system. For example, a maintenance strategy may be developed that calls for doing the maximum possible amount of maintenance at the lowest possible levels of the maintenance organization ("fix-forward"). This sort of

choice may influence both the system design (make the system as easy as possible to repair at lower levels of maintenance) and the skill requirements of maintainers (since more tasks will be accomplished at lower levels, more skills, and perhaps more training, may be needed for maintainers at lower levels).

A particular maintenance strategy may also explicitly contain elements that directly affect system design. For example, a maintenance strategy might require that some parts of a system be designed to be replaced at one level of maintenance, but not further repaired once removed from the system (design for discard). This could impact the designer's packaging choices for those components, since it is not necessary to access sub-components at lower levels to accomplish repair.

Operational Tempo. A third intermediate driver is the operational tempo (OPTEMPO) for the usage of systems. OPTEMPO is any one of a number of usage rates for a system. For example, an OPTEMPO for a wheeled vehicle may state that one copy of the system will be driven 5,000 miles per year. Or, one copy of a howitzer system may be expected to fire 300 rounds per day. The importance of OPTEMPO as a maintenance function driver is that the frequency of most maintenance tasks is correlated with usage rates. In general, the more a system is used, the more most maintenance tasks will have to be performed. OPTEMPO is derived from the Operational Mode Summary and Mission Profiles (OMS-MP) that are developed to describe system utilization. The OMS-MP is initially developed to support the O&O plan, and refined during development of the ROC.

Driven Factors

In general, the remainder of the elements and factors illustrated in Figure 1 may be thought of as driven by the several driver factors discussed above. As illustrated, many of the driven factors are themselves drivers or at least partial determinants of other factors. In Figure 1, an attempt has been made to identify the influences that impact successively driven processes or determinations. For example, maintenance MOS determinations are driven by a number of inputs, including the following:

1. MOS goals and constraints embodied in the O&O concept for the system.

2. Probable aptitude distribution in the projected manpower pool.

3. KSA requirements associated with maintenance tasks to be performed on the system.

4. Skill demands of system-associated support personnel performance requirements.

5. The maintenance strategy selected for the system.

Specifying the exact influences of each of these driver factors on the driven determinations or processes is beyond the scope of the present effort. Additional work is needed to identify the nature of specific influences and the extent to which these influences can be manipulated in the system development process to impact the maintenance demands of new systems.

No attempt is made here to explain each node and influence link depicted in Figure 1 individually, as the Figure is reasonably self-explanatory. However, several important features of the model as depicted are worth special mention:

The model is depicted so that the system maintenance burden is a concentrating point for the influence of previous driver and driven factors. This is somewhat misleading with respect to later driven factors, since these factors are also influenced by operations and support requirements that do not appear in Figure 1. It should be kept in mind that MANPRINT must consider all aspects of the MPT problem, not only those related to maintenance. The focus of the present effort is on the maintenance component of systems, so attention has been restricted to factors that influence maintenance. However, the patterns of influence of various driver and driven factors are expected to be similar for operations and support functions.

Many of the driven elements of the model that appear to the right of the maintenance burden have propagated influences that are not well characterized. While the patterns of influence depicted in Figure 1 are well-established in terms of existing MANPRINT, acquisition, and logistical support analyses, no generalizable quantitative relationships between factors appear to be established. The driver factors model is based on logical analysis and knowledge of the information flows in the system acquisition process, and makes no attempt to characterize quantitative influences. However, the flow of driver influence in this model very roughly corresponds to the phasing of when determinations become firm in the system acquisition process. Thus, decisions and determinations on the left side of Figure 1 occur relatively early in the system acquisition process, while driven factors toward the right side of the Figure are finalized later in the acquisition process.

The supporting analyses and determinations for each of the driven factors are iterative (or should be) over successive phases of the acquisition process. The iterative nature of the analyses supports attention to likely impacts on system MPT factors from early in the acquisition process (see Appendixes D and E), but only if the analyses are initiated early enough in the process. If analyses are started early and iterated at appropriate points in the acquisition process, it

should be possible to determine whether early concerns with regard to maintenance and other system performance and support factors are dealt with at later points in the process. The static picture of the relationships between driver and driven factors in this model may prove to be a point of departure for developing a dynamic process for monitoring the impacts of drivers (and changes in drivers) on various driven factors.

Model Dimensions

The model of demands that impact system maintenance is shown in Table 1. This model has two dimensions:

1. Type of Issue: Policy, MPT, Design, or Logistics.

2. System Life Cycle Issues: Acquisition or Operational.

Type of Issue

The first dimension, type of issue, separates the identified demand factors by the types of decisions and concerns they represent. For example, the category of policy issues contains factors that are impacted upon by policy decisions. MPT issues, design issues, and logistics issues can be similarly defined.

System Life Cycle Issues

"System life cycle issues" refers to the point in the acquisition, deployment, and use cycle at which the factor is initiated or becomes most relevant.

This dimension has two levels: acquisition and operational. The factors identified as being acquisition issues are ones for which decisions are initiated during system acquisition. The factors identified as operational issues are those which may have initially been driven by decisions made during system acquisition, but reflect the realization of those decisions. Operational issues are divided into two groups:

1. Factors that can potentially compensate for burdens to the maintenance system not under the maintenance system control.

2. Factors that are "given" and not under the control of the maintenance system.

Table 1

Maintenance Demands Model

Type of Issue	System Life Cycle Issues		
	Acquisition Issues	Operational Issues	
		Potential Compensatory Factors	Givens
Policy Issues	Levels of Repair Allocation of Tasks Maintenance Concept Maintenance Strategy Maintenance Perspective Force Structure (TOE) O&O Plan	Promotion Flow	Extended Storage of Equipment Distractors OPTEMPO
MPT Issues	Planned Manpower Training Personnel KSAs Force Structure (TOE) Personnel Mix Publications	Actual Manpower Actual Personnel KSAs Training Motivation Diagnosis TMDE Use Management & Supervision Formal Training OJT Tool Control Preventive Maintenance Retention Publications Use	System Operation System Status Reporting Crew Preventive Maintenance Migration into CMF

Table 1 (Continued)

Maintenance Demands Model

Type of Issue	System Life Cycle Issues		
	Acquisition Issues	Operational Issues	
		Potential Compensatory Factors	Givens
Design Issues	Maintainability Design Automatic Fault Diagnostics (BIT, BITE, ATE) Parts Commonality Planned RAM Acquisition Strategy Testibility Design		Achieved RAM
Logistics Issues	Facilities Publications Spare Parts and Expendables Provisioning	Tool Control	Spare Parts Availability

Factors

Factors were selected based on their identification in the literature as having major impact upon actual maintenance burden. However, within the context of the literature reviewed, there were many more factors mentioned than are presented in this model. It was determined that many of the factors identified in the literature could be subsumed under the more global factors included in the model. In addition, these global factors seem to be at a level appropriate to application to or integration with logistics and personnel models currently employed by the U.S. Army during system acquisition.

Although an extensive review of the literature was undertaken, there is an apparent lack of research on the topic of maintenance in the Army which documents specific impact factors, their relative impacts, and their interactions. Thus, potential factors of importance may have been omitted from the model. As it stands currently, many assumptions must be made concerning the interactions between factors, including the impact of including minor variables under more global variables.

Policy Acquisition Issues

There are seven maintenance impacting factors identified as policy issues for whom decisions are made during the acquisition process:

1. Levels of Repair;
2. Allocation of Tasks;
3. Maintenance Concept;
4. Maintenance Strategy;
5. Maintenance Perspective;
6. Force Structure; and
7. O&O Plan.

Levels of Repair. Levels of repair refers to the number and types of levels of repair that are designated to support a materiel system. For most materiel systems, there are three levels of repair: unit, intermediate, and depot. The Army Aviation system also has three level levels of support: Aviation Unit Maintenance (AVUM), Aviation Intermediate Maintenance (AVIM), and Corps AVIM. Although the Army usually selects one of these two configurations for the definition of the maintenance concept for a system, occasionally other configurations will be seen, for example two levels (Nauta, 1983).

For each level of maintenance, there are specific constraints on the types of tasks that may be performed and the types of personnel who

may be utilized to perform those tasks (see AR 750-1 for specific detail). For example, at the unit level, the maintainer's tasks usually consist of performing preventive maintenance, scheduled inspections, lubrication, minor adjustments, and replacement of "black boxes" (Nauta, 1983).

At each level of repair, personnel with certain skill levels to perform at particular proficiency levels are normally assigned. According to Nauta (1983), the Army regularly assigns personnel of lower skill levels to the unit level, moderate skill levels to intermediate (direct support), and the most highly skilled personnel to intermediate (general support) and depot levels.

In that decisions concerning the levels of repair determine to some extent the types of tasks performed at each level, such decisions also influence the training that will be developed for personnel at each level. Thus, the selection of the number and types of levels of repair impacts maintenance by constraining the types of tasks that may be performed at each level, who performs those tasks, and the training they will receive.

Allocation of Tasks. Although decisions concerning the number and type of levels of repair in general determine the types of tasks to be performed at each level, further analyses are required to determine the exact allocation of tasks to each level. Information concerning the design of the materiel system, its expected reliability, availability, and maintainability (RAM), expected available Automated Test Equipment (ATE), Built-in-Test (BIT), or Built-in-Test Equipment (BITE) design and capabilities, and personnel information are used in the analyses. Data from these analyses can result in the Maintenance Allocation Chart (MAC) for a system (Nauta, 1983).

The MAC contains a listing of maintenance tasks, their expected frequency of performance, the length of time required to perform each task, equipment needed to perform the task, the number of persons required to perform the task, and the MOS and skill levels of the maintenance personnel performing the task. The MAC is used in the development of maintenance training and as an input into the manpower allocation and personnel selection processes.

According to Nauta (1983) and Kokenes (1987), the allocation of tasks affects the maintenance in the following situations:

1. The actual time for task performance or frequency of performance differs from expected, thus negatively affecting maintenance scheduling and possibly resulting in the non-performance of the target task or tasks (Nauta, 1983).

2. The allocated tasks are actually performed by levels of maintenance other than the echelon responsible for the task, thus requiring personnel to perform tasks for which

they are not trained. Nauta (1983) cites this as a problem occurring with the M1 tank.

3. Allocated tasks which are supposed to be trained via on-the-job training (OJT) are not trained, due to lack of motivation or time by the personnel involved, thus resulting in improper performance of tasks (Kokenes, 1987).

4. The MAC is designed for a European-theater conflict scenario, rather than for implementation during other forms of conflict and peacetime. According to Nauta (1983), there are very few materiel systems that have contingency MACs available for situations other than the doctrinally prescribed one.

Although there are methods by which the MAC may be altered based on maintenance data for a system once it is fielded, according to Kokenes (1987), modifications to the MAC are rarely made. If changes are necessary, the process may require several years for the revision and implementation of new MACs.

Maintenance Concept. Maintenance concept refers to both the approach for maintaining a system and the levels of maintenance (and associated personnel) required for performing the tasks. This maintenance concept for a materiel system encompasses more than the system maintenance strategy.

The determination of a maintenance concept for a materiel system influences the maintenance function by creating limitations on the development of the MAC, selection of personnel, selection of maintenance locations, and support.

Maintenance Strategy. Maintenance strategy refers to the overall approach for maintaining a system, for example "fix-forward" or "recover and repair." The selected maintenance strategy will determine the levels of repair to include in the maintenance system, the major types of task allocated for each level, and how those levels are supplied (Nauta, 1983). For example, under current maintenance strategies, lower levels of repair usually replace components and send the faulty ones off for repair by the next higher level.

Selecting a maintenance strategy impacts the maintenance function by constraining the development of the MAC (and therefore training), the selection of personnel for particular tasks, the allocation of personnel, and the selected parts supply system.

Maintenance Perspective. Maintenance perspective refers to the type of military scenario in which maintenance will occur. There are several scenarios that impact the design of the maintenance system: peace, low level conflict, conventional war, and nuclear war. The usual perspective is a European theater, conventional war scenario. The perspective selected will affect the maintenance strategy selected,

which in turn impacts the MAC, the selection of personnel, training, the allocation of personnel, and the selected parts supply strategy (Nauta, 1983).

Force Structure. Force structure, as a policy issue during acquisition, refers to the consideration made at this time with regard to force make-up and organization that may have later repercussions upon the maintenance burden. These decisions and considerations include the number and types of MOSs a maintenance career field will have, the numbers of personnel of each skill level to be assigned to an MOS, the expected rate of promotion for personnel at each level, requirements for promotion, and the expected rate of recruitment of personnel to feed the MOSs in the career field.

If incorrect decisions or assessments are made during the acquisition process concerning those issues mentioned above, the result may be an unstable or unsuitable force structure. For example, Vine, et al. (1980) found that in the Army Aviation maintenance career management field, decisions concerning force structure resulted in a structure that had so many mid-level (E-5) slots, that all lower skilled personnel were assured of attaining them, often with no requirements for attaining a particular skill level before promotion. Because of this situation, there were many mid-level personnel who lacked the KSAs required for the maintenance performance expected of them.

O&O Plan. Although the O&O Plan was not specifically identified in the literature as an important demand factor for the maintenance component, it is. The O&O Plan is important because it lays the groundwork for the actual maintenance requirements determination. The O&O Plan contains information to guide the development of the maintenance concept, levels of repair, and the maintenance strategy to be employed for the materiel system.

MPT Acquisition Issues

There are six factors identified as MPT acquisition issues. They are:

1. Planned Manpower;
2. Training;
3. Personnel KSAs;
4. Force Structure (TOE);
5. Personnel Mix; and
6. Publications.

Planned Manpower. Planned manpower refers to the planned allocation of personnel to a particular task. This factor is concerned with the number of personnel of a particular skill level who are assigned to a level of repair. Manpower determinations are based on the numbers of personnel required for tasks listed in the MAC, the number of personnel of the required MOSs expected to be available, the number of sorties or

engagements expected for the system (OPTEMPO), and the expected RAM. Manpower allocations are presented as the TOE (Nauta, 1983; Kokenes, 1987).

Manpower may affect the performance of maintenance in two ways. First, the number of personnel assigned to a particular MOS and skill level in a unit may not equal the number allocated by the TOE. In this case, maintenance is adversely affected because there are not sufficient personnel to perform the work (Kokenes, 1987; Harz, 1981). Second, if any of the data on which allocations are based are faulty, or budgetary decisions require a cutback in personnel, then too few personnel may be allocated for performance of maintenance tasks (Kokenes, 1987).

Training. Training as an MPT acquisition factor refers to decisions concerning the training to be developed for the materiel system. Training has been identified by several authors as a major factor constraining the performance of maintenance (Harz, 1981; Nauta, 1983; Kokenes, 1987). The content of training is dependent on:

1. The tasks listed in the MAC;
2. The expected RAM of the system;
3. The expected capabilities of all test, measurement, and diagnostic equipment (TMDE) and performance aids available for the system;
4. The skill levels required;
5. The expected manpower availability;
6. The expected quality of personnel available;
7. The OJT that will occur; and
8. The availability of resources for institutional training.

A negative impact on maintenance resulting from training, noted by Nauta (1983), occurs in situations in which any of the inputs into training development are faulty. For example, cases have occurred in which BIT, BITE, or ATE capabilities do not perform to expected levels (Nauta, 1983; Harz, 1981). This means that a maintainer may be required to perform diagnostic tasks for which he or she has had little training.

Personnel KSAs. Personnel KSAs here refers to the identification of skills, knowledges, and abilities necessary for the performance of a task.

During the development of maintenance requirements for a system, personnel requirements are determined in accordance with the Manpower

Requirements Criteria (MARC) regulation (Nauta, 1983; Kokenes, 1987). This regulation requires that the types of tasks that will be performed by maintainers (based on all available system design and system support information) and the skills necessary to perform those tasks (derived from comparisons with similar systems) should be considered in the determination of the appropriate MOS and skill level for each task. If there is no appropriate MOS, then the Army may be required to create one. Information from the MARC is used in the development of the MAC, which, in turn, is used to develop training and allocate manpower. If the analysis of skills is incorrect, due to a base of incorrect data, then the determination of MOS and skill level requirements may also be in error. Errors from MARC considerations will impair maintenance training, manpower allocation, and maintenance performance.

Force Structure (TOE). A factor related to both manpower and personnel is the force structure and its development. The decisions concerning the force structure are reflected in the BOIP, QQPRI, and the TOE. The TOE specifies the personnel and equipment to be allocated to a level of repair. Decisions for the development of these documents are partly based on the MAC and MARC considerations (Kokenes, 1987). If errors exist in the input to the force structure development process, maintenance may be impaired by the inadequate allocation of appropriately skilled manpower and equipment (Kokenes, 1987). Such inadequacies may result in: 1) longer time requirements for the performance of tasks; or 2) non-performance of tasks.

Personnel Mix. Personnel mix refers to the mix of skills and the numbers of people needed for a level of maintenance. This factor covers both uniformed and civilian personnel (both contractor-supplied and government personnel) who may be utilized in a maintenance role.

The decision as to personnel mix is made during the acquisition process. It is based on the maintenance strategy, maintenance scenario, and levels of repair selected for a system. In the recent past, the Army has relied heavily on civilian maintainers, contractors, and Army employees (both U.S. cities and foreign nationals, in overseas postings), to supplement soldier maintainers (Wilk, et al., 1986). This reliance on civilian maintainers may be the result of a peacetime maintenance scenario.

The results of the MARC analysis are used to determine the mixture of skills and numbers of people required for maintenance performance. These decisions include the determination of the role that civilian maintainers will play. In the past, the Army has relied heavily on civilian maintainers to supplement their own personnel (Wilk, et al., 1986) This reliance is very reflective of a peacetime maintenance perspective.

Publications. Publications, in the context of maintenance, are the technical documents used by the soldier to aid in the task at hand. In order for these documents to be useful to the maintainer, they must

be: 1) available; 2) accurate; 3) current; and 4) pertinent to the task at hand. The maintainer must also know how to use the documentation.

SMEs indicated to Harz (1981) that often maintenance documentation seems to make the task more difficult. Documentation may make the task more difficult than it actually is by containing: 1) out-dated information; 2) distracting or non-pertinent information; 3) unclear or incomplete instructions; 4) confusing formatting; and 5) information or presentation style inappropriate for the intended user.

The outcome of poor or incomplete maintenance documentation may be lower maintainer efficiency because of longer times or lower quality of performance (Harz, 1981).

Design Issues During Acquisition

Six factors that pertain to design issues during system acquisition are:

1. Maintainability design;
2. Automatic fault diagnostics (BIT, BITE, and ATE) design;
3. Parts commonality;
4. Planned RAM;
5. Acquisition strategy; and
6. Testability design.

Maintainability Design. Several authors have indicated the importance of this factor for the maintenance burden (e.g., Nauta, 1983; Lewellen, 1985). Within this factor fall human factors engineering and safety aspects of system design. If a system is not designed with both the operator and maintainer in mind, then the maintainer's tasks may be more difficult than if consideration is given to his or her role. System design affects the tasks that are required of the maintainer, the personnel who will be required to perform the tasks, and the number of personnel required.

A system whose design is optimized for ease of maintainability may place less of a burden upon the maintenance component than a system whose design is less conducive to maintenance. On the other hand, designing a system that is optimal for maintenance may be costly in other ways. For example, it may be more expensive to acquire, less efficient to operate, or place extreme burdens on the supply system.

SMEs in the Harz (1981) study also identified system design as an important factor in the performance of maintenance. However, they were of the opinion that if system optimization for maintenance is not practical, training could be designed that would allow the maintainer to be as efficient as he or she would have been given an optimal system. Some impacts of this tradeoff are also discussed by Roth and Ditzian (1986).

Automatic Fault Diagnostics. The Government Accounting Office (GAO) (1987b), Fredrickson, et al., (1987), and others have focused on the impact of automatic fault diagnostics such as BIT, BITE, or ATE design on maintenance performance. The role of automatic fault diagnostics for maintenance is to serve as diagnostic tools for the maintainer. Although the intent behind the development of automatic fault diagnostics is to increase the efficiency and reliability of maintenance performance, the inclusion of these aids in systems has been problematic for seven reasons.

First, the aids often do not diagnose to a single component (GAO, 1987b; Fredrickson, et al., 1987). Instead, aids fault isolate to a cluster (ambiguity group) of suspect components. This means the maintainer is required either to attempt further diagnostics, swap components in and out until the fault is fixed, or replace all components within the identified cluster. If the maintainer is not trained in diagnostics, he or she may replace the wrong component, thus requiring re-test and re-repair. If the maintainer removes and replaces all components from the suspect cluster, then the next higher level of repair will be required to fault test several good components, thus increasing their workload. It has been observed that between 4 and 43 percent of all removed components are not faulty (Orlansky and String, 1981).

Second, automatic fault diagnostics often isolate only the first instance of a fault encountered in the system, rather than isolating all faulty components. The maintainer is required to isolate the first fault, take corrective action, and then re-test. If a second fault is indicated, the maintainer must repeat the diagnostic and repair steps, until all faults have been isolated and fixed. If all faults were indicated concurrently, the maintainer would require only one cycle of test, repair, and then re-test, rather than one cycle for each fault in the system. Multiple and propagated faults are not uncommon.

A third problem with the design of automatic fault diagnostics is that some configurations are designed so that the maintainer must isolate an error based on a pattern of indicators, rather than a simple "go" or "no go" indicator for individual components (GAO, 1987b). This problem is often the result of ambiguities in design specifications for the test equipment. This problem influences the type and level of difficulty of task the maintainer must perform to use the diagnostic aids efficiently.

Fourth, sometimes indicators are not optimally located for examination. Again, this problem affects the level of difficulty of the task requirements for the maintainer.

The fifth problem is that the automatic fault diagnostics that are ultimately delivered with the materiel system rarely meet the false readings specification (GAO, 1987b; Fredrickson, et al., 1987). In other words, the level of false readings often is much higher than the maintenance and supply systems have been designed to handle. There are

two types of false readings: false positives in which good components are identified as faulty, and false negatives, in which the automatic fault diagnostics do not detect the fault. In the first case, maintainers may request a new component, replace the existing one, and send the removed component for re-test to the next higher level of repair. This burdens the next level with the task of re-testing good components and the supply system with requests for unnecessary components. The impact on the maintenance system in the case of a false negative is: 1) releasing a system that is not mission ready to the operational force and thus potentially endangering other personnel; or 2) requiring time and personnel to take diagnostic action without the aid of the automatic tools.

The sixth difficulty for maintenance attributable to automatic fault diagnostics is the result of BIT or BITE integration with the operational system. As the name suggests, BIT and BITE capabilities are built-in or integrated with the operational system. In order for the BIT or BITE to operate, it must have access to the components of the system it tests. If the BIT or BITE is too well integrated into the components it tests, its own performance may be compromised by faults within those components. Additionally, if the whole system goes down, the automatic fault diagnostic capability is lost.

These first six problems associated with automatic fault diagnostics described here will stress maintenance, unless the maintainer is able to compensate for the inadequacy of automatic tools (by relying on his or her knowledge of diagnosis or other available tools). However, diagnostic skills are not stressed in the training of maintainers, because there is the assumption that maintainers will either not need them or will learn them through OJT. Training may be developed with the knowledge that maintainers will have automatic fault diagnostics (with expected capabilities) available to them, and, thus, they will not need extensive diagnostic skills. An additional assumption that may occur as training concepts are being developed is that there will be experienced diagnosticians to take over when they are needed. But as mentioned earlier, personnel assignments often do not meet the specified allocation levels because of availability of personnel, distractors, and modifications in Army policy. A lack of qualified personnel may produce at least an additive effect with automatic fault diagnostic problems on the capability of the maintenance system to return equipment to the field.

Finally, BIT, BITE, and other automatic fault diagnostics require their own maintenance function and all that entails. This requirement can increase the maintenance burden for a system by expanding the need for manpower, personnel, training, and logistic support for maintaining the automated diagnostic aids.

Parts Commonality. Although commonality of parts between systems or between sub-systems has not specifically been identified in the literature as a factor affecting maintenance, its potential impact is obvious. Having replacement items that may be used in several systems

or sub-systems could have a positive effect on the maintainer's ability to have supplies available. If controlled substitution is a doctrinally acceptable alternative, then it could occur when a system with parts interchangeable with the system under repair is available. However, substitutions may result in a greater burden to maintenance by placing another system in the repair queue.

Parts commonality would also reduce the quantity of system-specific training needed, because personnel could receive training on common parts once, and then be expected to generalize their knowledge to all systems in which those parts are used.

Planned RAM Issues. Planned RAM of a system refers to issues such as the expected frequency of maintenance for the system and its subsystems, the expected length of time required for maintenance, the specified maximum length of time the system is down, and any specific restrictions or aids that apply to the maintenance of the system (Lewellen, 1985).

The planned RAM for a system impacts the maintenance burden in several ways. The estimates of RAM, specified by the Army and then supplied by the materiel system contractor, are used to develop maintenance system requirements. These estimates are used in the development of maintenance schedules, supply system determination, manpower allocation, MAC development, facilities requirements, training, and documentation (Nauta, 1983).

Estimates of RAM supplied by the contractor or defined in the specifications for the system are often not met by the final product (Nauta, 1983; Lewellen, 1985). Unfortunately, there are not contingency plans built into the development of the prime item support system to account for the discrepancy between predicted and actual RAM. Thus, many aspects of the maintenance system that depend upon RAM information will require post hoc modification once the system is fielded.

Acquisition Strategy. Acquisition strategy refers to the overall approach the Army takes when acquiring a specific materiel system. There are two primary approaches that may be taken: 1) purchase an off-the-shelf or NDI; or 2) fund the development of a system to fulfill Army needs. The decision to use NDI occurs if during the market survey portion of system acquisition it is determined NDI exists that will fill the Army's requirements.

The decision to acquire NDI may potentially reduce the maintenance burden due to the availability of established contractor support systems. Such support systems may include training, documentation, warranties, etc. NDI may impair maintenance if contractor support materials do not meet Army standards, thus creating a need to bring them up to standard (MRSA, 1985).

Testability Design. Testability design for a system consists of the design considerations made that allow for ease in system diagnostic

testing. Such considerations include designing the system so that: 1) test point readings are easy to make and interpret; and 2) connections for external test devices are available.

Lack of consideration of system testability may affect the maintenance function by creating a situation in which diagnosing such problems become difficult requiring skilled manpower for which planning may not have occurred. Such a difficulty resulted when a contractor failed to include TMDE connectors and test circuits needed to connect with depot TMDE as part of the design characteristics for a track vehicle. This error was discovered at a point during acquisition at which correction to the system design would have been extremely costly and would have delayed fielding (MRSA, 1985).

Logistics Issues During Acquisition

Three logistics acquisition factors seem to impact the maintenance burden. These are:

1. Facilities;
2. Publications; and
3. Spare parts and expendables provisioning.

Facilities. Facilities refers to the physical environment in which maintenance function takes place. As such, it includes the design of the physical plant, protective devices or clothing that may be needed, and the ambient environment. Harz (1981) identified facilities as a factor of lesser importance, but it has an effect, nevertheless. Existing data suggest that if facility design and environment are not considered, maintainer efficiency will be substantially reduced (Harris, 1985; Kane, 1984).

According to SMEs participating in the Harz (1981) study, in order to optimize maintainer performance, facilities must be designed to allow efficient task performance. Thus, facility design must be based on information concerning: 1) the maintenance tasks to be performed; 2) other tasks that may be performed within the same facility or environment; 3) the ambient environment in which the facility will be located; and 4) the types of conditions under which tasks will be performed.

In cases in which facility design or environment are not conducive to efficient performance, or tasks must be performed while wearing protective garments, maintainer performance may decrease in quality and quantity. Harz (1981) suggests that training for and practice within such situations may help to alleviate problems associated with performing in less than optimal conditions.

Publications. Publications as discussed earlier, are technical documents used to aid the Army maintainers as they perform their tasks. Publications, as a logistic support issue, refers to the coordination

that must occur between publication development and system acquisition. Publications must reflect, as previously mentioned: 1) current and complete information; 2) useful format; and 3) written for the appropriate audience. However, at times, due to difficulties coordinating publication development with either system acquisition procedures or post-deployment system modifications, publications may be issued that do not conform to the fielded system (MRSA, 1985).

When maintenance publications are not current with the system, maintainers are likely to not use them. They will rely on general troubleshooting skills, if they have them, swapping parts until the system is operational, or send it to the next level of repair.

Spare Parts and Expendable Provisioning. During system acquisition, decisions are made concerning the system by which spare parts and expendables will be stocked and made available to maintainers. These decisions can affect the maintenance burden by defining certain tasks to be performed during maintenance.

Operational Policy Issues: Compensatory Factors

One compensatory factor identified as reflecting a policy issue that influences maintenance is the set of decisions made concerning promotion flow. The flow of promotions (number and rate) of personnel through the MOS or career management field (CMF) may create a situation in which certain slots are filled with poorly qualified personnel. This may occur due to decisions initially made during acquisition, but may also occur due to later-implemented policies (Vines, et al., 1980).

Operational MPT Issues: Compensatory Factors

Twelve factors were identified as potential compensatory factors that affect the maintenance burden once the system is operational. These factors are:

1. Actual manpower;
2. Actual personnel KSAs;
3. Training motivation;
4. Diagnosis;
5. TMDE use;
6. Management and supervision;
7. Formal training;
8. OJT;
9. Tool control;
10. Preventive maintenance;
11. Retention; and
12. Publications use.

Actual Manpower. Actual manpower refers to the number of personnel available to perform the task at hand. This number may or may not be as estimated or designated during the materiel acquisition process. According to Harz (1982), cases occur in which the difference in the number of available personnel and the number designated by the TOE impairs the performance of maintenance. In such cases, the planned manpower availability may be accurate for the task, but because of extenuating circumstances, this availability cannot be realized within the context of the level of repair.

Actual Personnel KSAs. During the acquisition of a system, informed assumptions are made as to: (1) the KSAs that personnel will have after they have completed training (both formal and OJT), and (2) the applicability of those KSAs for the performance of the job. There are steps taken during the acquisition process to ensure that personnel will be appropriately trained. However, in studies by Harz (1981) and Vines, Johnston, Pratt, and Fee (1980), SMEs reported that often the personnel available to perform maintenance tasks do not have the requisite KSAs to do so. This problem may be the result of many factors, such as deficiencies in personnel KSA requirements identified during acquisition, policies concerning force structure or promotion flow, inability to retain personnel, etc.

Training Motivation. SMEs participating in a study by Harz (1981) identified training motivation as a major impact on maintenance. Training motivation refers to the desire on the part of personnel to receive OJT or to take part in other forms of supplementary training and to the desire on the part of the supervisors to provide training.

Currently, time is at least nominally set aside at various levels of repair for training activities. However, many maintainers do not recognize the need for the continuation of their training. Therefore, they may decide not to invest intellectual effort and practice time in the endeavor (Harz, 1983).

Additionally, supervisors mentioned having little available time for training (Kane, 1984). Because of this lack of time available, supervisory personnel are not likely to urge their people to participate in training-related activities.

Supervisory personnel are also often called upon to perform OJT on the maintenance of new items, the use of new TMDE, and the use of technical publications. Many times supervisory personnel do not have sufficient background concerning the information they are to teach, or are uncomfortable in the role of educator (Harz, 1981). Because their insufficient background or discomfort, supervisory personnel lack motivation to train their subordinates (Nauta, 1983). If personnel are not motivated to learn and supervisors are not motivated to train, then the unit will fall behind in the capability to perform required maintenance.

Diagnosis. Harz (1981) and Nauta (1983) identify maintainer diagnostic skills as an important factor in the performance of maintenance. It may constrain the performance of maintenance by interacting with training factors. In work by Harz (1981), it was found that maintainers are asked to perform diagnosis tasks for which they are not trained. This situation comes about in three ways. First, tasks that are allocated by the MAC to one level of repair may be performed by a different level. Second, there may be cases in which the MAC or TOE in effect does not reflect the current maintenance scenario. The third possibility is that the MAC reflects the expected capabilities of aids (e.g., BIT, BITE, or ATE) supplied to the maintainer to augment diagnostic performance. Unfortunately, these performance aids often do not augment the soldier's capability to an appropriate level. This requires further troubleshooting by the soldier, a task for which he or she may not be adequately prepared (Fredrickson, et al., 1987; GAO, 1987b; Nauta, 1983). The root of all three of these situations is the MAC and, consequently, the training received by the maintainer.

A maintainer's inability to diagnose system problems correctly often results in the replacement of components not requiring maintenance, thus creating burdens for higher levels of maintenance which must re-test the "faulty" component (Orlansky and String, 1981). Wholesale replacement of parts which may or may not be faulty also places stress on the parts supply system. On the other hand, the maintainer may completely overlook the faulty component and possibly return a faulty system to service (Orlansky and String, 1981). Another outcome of the maintainer's lack of diagnostic skill may be an increase in time required to perform the assigned maintenance task, thus impairing the scheduling of maintenance tasks and the allocation of personnel to perform the tasks.

TMDE Use. The use or lack of use of TMDE by maintainers appears to be a major factor that places demands on the maintenance system (Harz, 1981). SMEs participating in the Harz study felt that there was a negative impact because of improper use or complete lack of use of available TMDE. Maintenance personnel often prefer not to utilize TMDE because of: 1) lack of training in use of the equipment; or 2) awareness of the inaccuracy of diagnosis supplied by the equipment. If the maintainer does not use TMDE, he or she must employ other diagnostic methods to isolate the problem. Maintainers attempting to perform diagnosis may not be appropriately trained for such tasks. In addition, there is often the expectation that TMDE use and diagnostic skills will be trained by OJT. Potential OJT trainers often are not competent or have no desire to conduct training.

The lack or misuse of TMDE may have the same net result as the inability of maintainers to perform diagnostic tasks. That is, the maintainer may resort to a trial and error method of parts replacement and thus may replace components not in need of repair. These good components would then be sent to the next level of repair for re-test

and repair, thus burdening the next level with tasks that are not really required. The supply system might also be burdened with requests for replacement components that are not really needed.

Finally, without the use of TMDE, the maintenance task may take longer than the time allocated for its performance, thus impairing scheduling and personnel allocation. For example, when the maintainer requests a new part, he or she must wait until the part is delivered before continuing the diagnostic process. With the use of good diagnostic skills or aids, the waiting period will be reduced. The potential also exists for the maintainer to miss identifying a fault. Such missed faults could result in the return of faulty equipment to service, which may significantly impair mission capability.

Management and Supervision. In both the Harz (1981) study and the work done by Campbell and Kane (1986) for the Air Force, supportive and motivating management and supervision improved maintenance performance, whereas non-supportive supervision and management degraded it. Motivating management provides positive incentives for good performance, rather than relying on punishment. It was also reported that supervisors who are sensitive to their subordinates improve unit performance. Supervisors must be respected by their subordinates for their knowledge and skill in maintenance, their ability to delegate and schedule tasks appropriately, and to maintain control over the workforce and its resources. Without strong management and supervision, the performance level of maintenance may be reduced.

Formal Training. Formal training (or training supplied within the context of the institution) has been identified by SMEs in the study by Harz (1981) as having a profound impact upon maintenance. The opinion of the SMEs in the Harz study was that maintenance personnel often receive inadequate training within the institution. Tasks that are identified as non-critical are not taught at the institution. Quite often, however, these tasks turn out to be critical ones in the sense that incorrect performance of them places greater demands on the maintenance system.

OJT. OJT is another important factor impacting maintenance (Kokenes, 1987). As discussed in the training motivation section, poor or omitted OJT may degrade maintenance performance. As mentioned previously, supervisors are often reluctant to allot time for training. They are also sometimes uncomfortable with actually providing training. In addition, maintainers may not be motivated to take part in OJT because they do not see any obvious advantage for doing so.

When OJT is not performed or is poorly administered, the result may be inefficient or poor maintenance performed by personnel with lower KSAs than task performance requires. In order to reduce the negative impact that the non-performance of OJT has maintenance, incentives may be needed for administering and participating in OJT (Campbell and Kane, 1986; Harz, 1981).

Tool Control. Tool control impacts the actual maintenance burden when control is not maintained or supply is inadequate. SMEs report that the performance of maintenance tasks is frequently delayed because tools appropriate to the task are not available (Harz, 1981). It is the supervisor's responsibility to maintain adequate control over tool allocation, task scheduling, and replacement requisitioning.

Preventive Maintenance. Preventive maintenance consists of scheduled maintenance actions performed in order to avert a later need for replacement or repair actions. Within the maintenance domain, the major impact of preventive maintenance is with respect to scheduling and performance (Nauta, 1983; Harz, 1981). According to Harz (1981), preventive maintenance actions often are not performed except directly prior to scheduled inspections by outside personnel.

Lack of performance of preventive maintenance occurs for one primary reason: maintainers consider these tasks to be of lower priority than unscheduled maintenance tasks (Nauta, 1983). Due to limitation of resources, maintainers will schedule these tasks as the last to be done. They will either not perform them at all, or perform them in a cursory fashion, but complete the records as if those tasks had been done properly. The outcome of this type of behavior is: 1) the potential for later difficulties with the system, and 2) inaccuracies in the records that feed back to the policy-making and logistics agencies of the Army who have the power to influence the resources available to perform preventive maintenance.

Retention. Retention refers to the likelihood that personnel will stay within their MOS. The greater number of individuals who decide to remain in their MOSs and not transfer to other MOSs or leave the service, the greater will be the number of experienced maintainers available to perform complex maintenance tasks. According to Vine, et al. (1980), however, the Army has had problems recruiting and retaining personnel for certain maintenance MOSs and CMFs.

Publications Use. SMEs in the Harz (1981) study indicated that use of publications affect the performance of maintenance. Publications are useful if they are well-written, accurate, up-to-date, contain useful material, and can be used efficiently by the maintainer. If documentation does not meet these requirements, the efficiency of the maintainer's performance will be reduced.

It is often the case that documentation updates lag far behind actual fielded changes in the system. In this situation, maintainers must resort to knowledge acquired from other sources (such as discussions with personnel at other levels of repair or information based on experience with similar systems) to perform the tasks at hand. This behavior may lead to greater time for repair than if accurate documentation were available.

Even if maintenance documentation is accurate and useful, the maintainer must know how to make use of the information contained

in the documentation. Use of technical publications is not a topic that is stressed during the maintainer's formal training (Harz, 1981). Training the maintainer in the use of technical material is considered to be the responsibility of the maintainer's supervisor. As mentioned previously, supervisors often do not conduct OJT or do so poorly. The result is that the maintainer does not learn how to make use of the tools of his or her trade. These tools include technical documentation.

The ultimate effect of this factor on maintenance may be inefficiency in task performance by the assigned personnel.

Operational Logistics Issues: Compensatory Factors

Only one factor has been identified as a potential compensatory logistics factor during operations. That factor is tool control, which was discussed earlier within the context of compensatory MPT issues during operations. SMEs in the study by Harz (1981) indicated that tool control contributed significantly to the ability of the maintainer to do the job. The control of tools in and out of the shop usually is the responsibility of supervisory personnel. However, if tools are either completely absent or of inferior quality, the problem falls to the logistics support system for correction.

Operational Policy Issues: Given Factors

Three factors have been identified as reflecting policy issues in the performance of maintenance. These factors are:

1. Extended storage of equipment;
2. Distractors; and
3. OPTEMPO.

Extended Storage of Equipment. A factor that may influence maintenance (identified by SMEs in the Harz [1981] study), is the extended storage of equipment. The Army has materiel systems that are kept in storage for extended periods. These systems often are not subjected to periodic preventive maintenance or inspections while in storage. When the systems are removed from storage, they are inspected and repaired as necessary. However, because of the lack of maintenance during storage, many of the systems need extensive work to make them mission ready. As a burden to the maintenance system, the issue is whether it is less costly to perform maintenance on the system during its storage period or at the time of removal from storage. The opinion of the SMEs in the Harz (1981) study was that maintenance during storage was more cost-effective than performing the maintenance when the system is activated, since maintenance requirements in the former case are often less extensive than in the latter situation. This opinion is supported by findings presented in a special report about the 1987 POMCUS/REFORGER exercise (Peco Enterprises, 1988).

Distractors. A major impact factor identified by SMEs in both the Harz (1981) study and the Campbell and Kane (1986) study was the presence or lack of non-maintenance distractors. According to many authors, including Harz, a maintainer spends only approximately 20-30 percent of their time actually maintaining equipment. The remainder of the maintainer's time is taken up by three types of distractors:

1. Those pertinent to maintenance such as training and paperwork;

2. Those that are not maintenance-related, but are service-related, such as guard duty; and

3. Those that are not service-related, such as medical appointments and distractors related to family matters.

Distractors may degrade the performance of maintenance by removing personnel from the manpower pool. This means that there may be instances when there are not enough people of the appropriate skill levels or experience to perform maintenance tasks.

OPTEMPO. The operational tempo, or OPTEMPO, of a system refers to the planned usage rate for the system. It is the basis for system utilization expectations and planning based on those utilization rates. OPTEMPO for a system is presented in the system Operation Mode Summary/Mission Profile.

As a factor, OPTEMPO is initially determined during the acquisition phase. It is used for estimations of maintenance burden. The actual usage rate for a system may differ from the planned rate, however. Thus, the resulting actual maintenance burden may differ from the estimated burden.

Operational MPT Issues: Given Factors

There are four MPT factors that affect maintenance during operations that are not controlled by the maintenance system. Those factors are:

1. System operation;
2. System status reporting;
3. Crew preventive maintenance; and
4. Migration into CMF.

System Operation. A major given MPT factor identified by the SMEs in the Harz (1981) study as influencing maintenance is system operation. Many maintenance actions are the result of misuse or abuse of the materiel system by the operator (Harz, 1981; GAO, 1987a). Misuse or abuse problems seem to stem from deficiencies in operator training and a lack of operator supervision (GAO, 1987a).

If operators use equipment properly, the system might be mission ready for a larger proportion of the time, and the actual maintenance burden would be reduced.

System Status Reporting. The Government Accounting Office (1987a) found evidence that system operators are often negligent in the preparation of system status reports. The Harz (1981) study also mentions the potential negative impact on maintenance when such reporting is either not done in full or not done at all. This lack of reporting usually occurs for one of two reasons: 1) the operator does not want to accept responsibility for reporting an error he or she has made with regard to the system; or 2) there are no perceived benefits or enforced structure for preparing accurate status reports.

Several situations may occur as a result of faulty system status reporting. First, maintenance problems may not be identified before the next full system inspection. Second, in the case of partial completion of paperwork, some maintenance problems may be overlooked while others are corrected. Third, without complete and correct status reports, the maintenance databases used for making ILS decisions cannot be used with confidence.

Crew Preventive Maintenance. System operators are often required to perform preventive maintenance on the systems they operate. SMEs in the Harz (1981) study reported that a major negative impact on maintenance occurs when operators do not perform preventive maintenance or perform it incorrectly. Not taking required preventive measures may mean that equipment will need repair earlier and more frequently in its life cycle than would otherwise be expected. The maintenance support concept for a materiel system is based on the assumption that preventive maintenance will be performed correctly and in a timely manner. When this assumption is not met, an unplanned burden may be placed on the maintenance system.

Migration into CMF. Migration into the CMF is a given MPT factor. It refers to the fact that there will be personnel who will transfer into a particular maintenance CMF from other CMFs. According to a study of the Army aviation CMF (Vines, et al., 1980), migration into a CMF can have a profound impact upon maintenance because of: 1) skill levels which may not be comparable to personnel who had their initial training and experience within the context of the CMF; and 2) the requirements associated with training new personnel in the field. Often these impacts upon the maintenance system are not fully considered during the planning and acquisition stages.

Operational Design Issues: Given Factors

The design factor that seems to have the most impact on maintenance once a system is deployed is achieved RAM. Achieved RAM refers

to the actual reliability, availability, and maintainability values realized once the system has been fielded. It is a catch-all factor resulting from system design, system usage, spare parts and tool availability, manpower availability, personnel skill levels, automatic fault diagnostics capabilities and usage, and documentation. Discrepancies between planned RAM and achieved RAM occur frequently (see Nauta, 1983 for more information). Without further investigation into the elements that impact RAM values, however, it is impossible to determine why particular discrepancies exist and what steps are required to alleviate these problems.

Operational Logistics Issues: Given Factors

Only one logistics factor was determined to have a substantial impact upon maintenance once a system is in operation. That factor is spare parts availability. This factor is discussed by Harz (1981). Spare parts availability refers to: 1) quantity of parts available; 2) quality of parts; and 3) accessibility of parts. In the optimum situation, if a maintainer must replace a part, a replacement is available with minimum delay. This optimum situation may not be met, however, due to depletion of inventories by other maintenance groups and faulty supply lines. Other reasons for spare parts unavailability include inadequate planning, poor engineering or logistic support analysis (LSA) estimates of parts usage, poor provisioning, or unexpectedly high levels of parts usage.

When the optimum situation is not met, the maintainer (depending on the situation) has several potential options, but all options may place stress on the maintenance system. First, the maintainer may wait to perform the task until the part is available and in hand. This choice may impact the speed with which the system can be returned to service. Second, if a substitute for the part exists and is at hand or readily available, then the maintainer may opt to use the substitute as a replacement. This situation can occur if: 1) controlled substitution system has been approved; or 2) diverse systems have common parts. Obviously, one wishes to minimize the length of time the materiel system is out of commission. Thus, the maintenance system will work most efficiently when there are parts readily available.

DIRECTIONS FOR FUTURE RESEARCH

This report is the culmination of a first step toward developing methods to explore the potential influences of decisions and decision outcomes on maintenance demand and related MPT demands. Many variables that affect maintenance have been identified here, and their general influences have been described. Future research should attempt to move toward a more predictive, quantitative capability to assess the consequences of early decisions on maintenance-related characteristics of future systems.

To provide guidance for such research, the eight variable domains presented in the maintenance demand factors conceptual model were evaluated. The results of the evaluation are summarized in Table 2. The evaluation method is described below. First, general research approaches to addressing the influences of the variables in seven of the eight domains were identified. Three general types of approaches were identified in this process:

1. Modeling, with sensitivity analysis. This approach presumes the development of one or a family of simple-to-use, tractable computer-based models that can be used to explore the consequences of early acquisition decisions on the maintenance demand and MPT characteristics of systems. Such models could be based on the maintenance process model contained in this report, or on other approaches, such as derivatives of ARI's MANCAP model. Sensitivity analysis, using the model(s), would be used to address the consequences of varying early decisions on maintenance demand, the performance capability of the maintenance system, and MPT characteristics of the maintenance system. A companion document (Roth, 1988a) contains an evaluation of several candidate modeling approaches. A later subsection in this section outlines a possible technical approach to future research that combines modeling with sensitivity analysis and case studies.

2. Case studies. This approach involves focused studies of the decisions made about maintenance characteristics of systems in the acquisition process, the implementation of those decisions during system development, and the consequent maintenance-system and related MPT characteristics of fielded or developmental systems. The intent of such studies would be to refine knowledge about the effects of variables and factors identified in this report, and to develop initial concepts and data about relationships between decisions and consequences that could be used to

Table 2. Definition and Evaluation of Research Approaches

Life Cycle Impact	Type of Issues	General Research Approach(es) (All include Methods Development)	Term of Payoff	Magnitude of Payoff	Research Risk Level	Magnitude of Cost (Research	Recommended Priority	Comments
Acquisition	Policy	(1) Case studies (2) Modeling with sensitivity analyses	(1) Near-Medium (2) Medium-High	(1) Low-Medium (2) Medium	(1) Low (2) Moderate	(1) Low (2) Moderate	(1) High (2) High	Case studies to refine variables; modeling to examine consequences—perform in parallel?
Acquisition	MPT	Modeling with sensitivity analysis	Medium	Medium-High	Moderate	Moderate	High	Can combine with acquisition policy issues investigations
Acquisition	Design	(1) Case studies (2) Modeling with sensitivity analysis	(1) Medium-Far (2) Medium	(1) Low-Medium (2) Medium-High	(1) High (2) Moderate	(1) Low (2) Moderate	(1) Low (2) Moderate	Can combine modeling investigations with other domains; case studies mostly for critical incidents
Acquisition	Logistics	Modeling with sensitivity analysis	Medium	Low-Medium	Moderate	Moderate	Low	A lower priority domain; can combine with other modeling
Operational	Policy	(1) Survey or interview (2) modeling with sensitivity analysis	(1) Medium (2) Medium	(1) Low (2) Low-Medium	(1) High (2) Moderate	(1) Moderate (2) Moderate	(1) Low (2) Moderate	Survey of interview would confirm or refute results to date; modeling cannot handle some variables
Operational	MPT	(1) Survey or interview (2) Modeling with sensitivity analysis	(1) Medium (2) Medium	(1) Low (2) Medium	(1) High (2) Moderate	(1) Moderate (2) Moderate	(1) Low (2) Moderate	Modeling probably cannot handle all variables, but can be combined with other modeling
Operational	Design	-	-	-	-	-	-	Only one factor that would automatically be addressed in modeling studies
Operational	Logistics	Modeling with sensitivity analysis	Medium	Medium	Moderate	Moderate	Low	Can combine with other modeling investigations

guide development of the model(s) suggested above, and the application of the models and conduct of sensitivity analyses. Primary sources of information for such studies would be:

a. acquisition documentation (O&O plans and concepts, ROCs, ILS plans and documentation, SMMPs, etc.);

b. products produced during system development (LSA records, design documentation, FEA documentation, HARDMAN or ECA study results [if performed], QQPRI data, BOIP data, unit TOEs, design review minutes, user and technical test results, etc.); and

c. data that characterize the performance and problems of fielded maintenance systems (sample data collection reports, follow-on test and evaluation documentation, modification TOEs, manpower and personnel reporting data, and critical incidents collected from units using the systems in question).

Both fielded and developmental systems could be studied by this method. It is possible that some longitudinal or continuing studies of developmental systems might be appropriate, especially once modeling tools are available and could be used to develop recommendations regarding maintenance-influencing decisions.

3. Survey or interview methods. This approach can conceptually support both the case study and modeling approaches discussed above. It is envisioned that this approach would be used only when very specific topics are identified as target areas for additional information gathering. No large-scale survey or interview studies appear to be necessary, however.

After the research approaches for each domain were identified, each approach was evaluated on the basis of four variables:

1. Term of payoff. This refers to the amount of time before useful results, in terms of rules, principles, or techniques, would be realized from pursuing an approach. The approaches for each domain were rated as near-term (six months or less), medium-term (six to 24 months), or far-term (more than 24 months) on this variable. The payoff term estimates are approximate.

2. Magnitude of payoff. This refers to the likelihood that a particular research approach conducted in a particular variable domain could ultimately result in techniques or products of practical value to Army analysts and decision makers. This variable was rated as low, medium, or high.

The magnitude of payoff ratings are judgments by the authors.

3. Research risk level. This refers to the probability of research using a particular approach, in a particular variable domain, producing intermediate or ultimate results that can contribute to the development of useful and practical techniques or products. This variable was rated as low, moderate, or high, based on the authors' judgment.

4. Magnitude of research cost. This refers to the probable range of cost of performing research using a particular approach, in a particular variable domain. The ratings used are low (probable cost range under one person-year level of effort), moderate (probable cost range between one and four person-years' level of effort), and high (probable cost range over four person-years' level of effort). The high rating was not used for any of the approaches individually. However, if several approaches were pursued simultaneously or sequentially, the total research cost could easily fall into this range.

The ratings on each of the four variables were combined judgmentally to develop a priority recommendation for each of the research approaches and variable domains. The recommended priorities are: high (the domain and research approach are recommended as one of the first to pursue); medium (the domain and research approach should be pursued after higher-priority ones); and low (if resources are available, some value may be had from pursuing a research approach in this domain).

Comments were added to a tabulation of results to produce Table 2.

Suggested Research Method

A three-faceted approach to investigating the development of methods and techniques for assessing maintenance demand and associated MPT factors in systems is suggested. This approach will include further prioritization of channels of investigation through retrospective case-study analyses, developing model-based estimation methods, and applying the estimation methods to study systems currently in acquisition or product improvement. The three facets of this approach are summarized as:

1. Conduct case studies and perform strategic planning for model-based methods application. Further investigations are required to select, from the variables identified in this report, those with the highest potential research payoff in terms of practical and effective methods for use in MANPRINT. A case-study approach is recommended in the variable selection process.

2. Develop and explore the use of simple, cost-effective, and efficient modeling approaches to explore the potential consequences of selecting the variables on maintenance demand and MPT factors. A means of rapidly exploring alternative consequences of maintenance-impacting decisions upon maintenance-related factors is needed.

3. Apply the model-based methods in the context of on-going system acquisition efforts, to evaluate their merit, usability, and payoff. The methods should offer a means of rapidly examining the maintenance demand and MPT consequences of alternative decisions about system maintenance, even very early in the acquisition process. The acceptability and validity of using these methods should be determined through their actual application in system acquisition programs, with review of the outcomes with populations of likely users and decision makers who would utilize the results of such applications.

Case studies and strategic planning should be conducted first, to provide a basis for the other parts of the approach. Concurrently, or trailing slightly, model development and laboratory applications should be performed, to establish usability and face validity of the model-based methods. Then, applications should be attempted in on-going acquisition programs. However, iteration through the case study and planning process, and refinements of the initial methods, may need to take place after some practical experience has been gained in modeling-based tool application, and feedback is available on how well the methods perform.

The remainder of this section discusses a more detailed approach to each of these three facets.

Case Studies and Strategic Planning

The purpose of this facet of the approach is to select and prioritize specific variables and factors for investigation to determine the extent to which they can be used to evaluate system maintenance demand. The point of departure for this effort will be the maintenance demand factors model and driver factors conceptual models.

Initially, efforts should be made to select not more than a dozen specific variables from the higher priority variable domains discussed above. This selection will occur through additional examination of literature, discussion of topics with maintenance-knowledgeable SMEs, and case studies on selected acquisition cases. Some criteria for variable selection are: 1) likelihood of variables' having major influence on system maintenance burden (both task performance demand and MPT requirements); 2) ability to incorporate the variables in maintenance process models with relative ease; and 3) whether deter-

minations on the selected variables are made early in the acquisition process.

Concurrent with the initial variable selection, system acquisition cases to be used as case studies, both in a retrospective sense and as potential areas for testing and application of hypotheses and methods to be developed, should be identified. Some retrospective case studies (e.g., the ARI-sponsored "Reverse Engineering" studies) have already been conducted. Future investigations should take advantage of these studies to the extent they meet selection criteria.

Next, data on each case-study system should be gathered, and studies performed on each case. Retrospective data would be analyzed to identify specific variables that influenced the maintenance burden, or caused post-fielding maintenance MPT issues to arise. Other cases (ongoing acquisition programs) would be used to identify existing maintenance-impacting decision points, supporting analyses, criteria, and responsibilities. Additionally, current cases could be used as application testbeds for models or methods developed as a result of later activities in other facets of this approach.

The objective here is to target more precisely some or all of the maintenance-influencing variables for modeling and use of methods or methods to be developed. Detailed criteria should be used in the variable selection process, including: 1) the potential life-cycle impact of variables on supportability and maintenance performance; 2) the extent to which it may be possible to manipulate variables through acquisition process decisions; and 3) the potential scope and term of payoff of studies and applications relative to the variables.

As a result of the previous activities, a strategic plan for investigating maintenance decisions and developing methods for use in the acquisition process would be developed. The result would be a plan of action for model development, and model or other tool applications in on-going acquisition programs. The plan should specify specific acquisition or fielded systems cases most appropriate for investigation through: 1) further or more in-depth retrospective case studies; 2) specific modeling investigations and application of methods to support acquisition process decisions; and 3) monitoring of ongoing acquisition programs to identify additional critical variables and decisions that impact maintenance burden, as well as to assess the influences of variables already under investigation. Performing the initial case studies and developing the strategic plan should require about a one person-year level of effort.

Model Development and Modeling Investigations

A tractable, flexible, easy-to-use, low-cost maintenance modeling technique is of great potential value in assessing the influence of alternative policy decisions on maintenance burden and MPT requirements. In this facet of the approach, the objective is to develop and apply such models. The models to be developed could be based on the

generic process model presented in this report, elaborated to reflect the consequences of particular choices of maintenance strategy, maintenance concept, task allocation to levels of maintenance, equipment use rates, etc., as suggested by the maintenance demand factors and driver factors conceptual models and Army personnel allocation policies (e.g., MARC). An alternative basis for modeling that might be used is the generalized model approach based on MANCAP, presently under development by ARI.

One general approach is to utilize a tool such as MicroSAINT(TM) as a modeling support tool for maintenance models, providing for the use of outputs of combat models as a driver mechanism for maintenance demand. Using combat model output as a driver mechanism, rather than having an internal maintenance-demand driver, can simplify using the models and reduce data requirements. With the use of an external demand driver, a few (worst-case) demand scenarios can be developed and used with the maintenance models. This increases the usability and flexibility of the maintenance models, at reduced development cost.

Initially, an approach may be to develop maintenance models that reflect typical maintenance organizations, tasks, and support patterns for one or two general types of systems. The types of systems that should be chosen should be based on several criteria: 1) systems are readiness-critical; 2) systems are likely to sustain battle damage of various levels of severity; and 3) systems experience relatively high use rates in combat. These criteria reflect the likelihood of relatively high maintenance demands for these types of systems. High maintenance demand systems are likely to provide more opportunity to explore the effects of relatively small changes in driver variables when sensitivity analysis is conducted.

The types of systems selected should support building baseline-case models that can be easily modified to reflect maintenance task demand and organizations of emerging systems. Model development for one or two types of systems, and initial validation with test data sets, is projected to require about two person-years' level of effort.

Following initial model development and validation, a set of sensitivity analyses could be performed with respect to the maintenance-impacting variables selected. The purpose of these analyses would be to focus on those variables that have the most apparent leverage on maintenance system characteristics, in subsequent attempts at model application in ongoing acquisition programs. Initially, it would be preferable to perform a set of one-independent variable sensitivity studies. The perturbations to be introduced as a function of alternate decisions would first be identified. These would then be used to develop alternate model versions or parameter sets for model execution. The alternate cases would then be run against the models and the results examined. In selected cases, two- or n-independent variable sensitivity analyses might be performed later, depending on the findings of the one-variable analyses. Results of the set of sensitivity analyses could lead to the development of rules of thumb or general guidelines for evaluating the consequences of mainte-

nance policy decisions early in the acquisition process. It is estimated that sensitivity analyses following this approach would require from one to two person-years' level of effort.

Models Application and Refinement

Either immediately following, or concurrent with, the conduct of the one-variable sensitivity analyses, efforts should be made to apply at least one model in an ongoing acquisition program. The selected program should be at a very early stage of acquisition (pre-milestone one is preferred), and should not have had any maintenance strategy, concept, or philosophy determinations finalized--various alternatives should be under consideration. A baseline comparison system (or composite) should have been identified, from which to develop data to support development of a task-based model. Also, the acquisition manager(s) of the system should be amenable to using the program as a testbed for MANPRINT methods.

Datasets or alternate model versions should be developed to reflect each alternate maintenance system under consideration, in a sensitivity-analysis fashion. Each model or dataset would then be exercised, and the results used to trade-off the maintenance system alternatives against probable operational maintenance demand and MPT requirements. The acceptability and face-validity of this approach for supporting maintenance system decisions would be evaluated in concert with the involved analysts and acquisition manager(s), and needed changes to the methods identified.

Several iterations of the application process just described might take place, with interim improvements in the initial modeling approaches developed, or the decision guidance and methods produced. Incremental development and testing of the approaches and candidate methods provides a powerful approach to influencing the maintenance components of both current and future Army systems.

REFERENCES

Campbell, W. and Kane, W.D. (1986). Why can't maintenance cure its malaise? Air Force Journal of Logistics, Summer issue, 38-41.

Chenzoff, A.P. (1985). Decision processes and information requirements for integrated diagnostics and battle damage assessment. Valencia, PA: Applied Science Associates, Inc.

Clements, D.T. (1984). Design of an experiment to examine repair process errors of military vehicle mechanics (ADA 152229). Master's Thesis. Melbourne, FL: Florida Institute of Technology.

Department of the Army. (1987). Army Regulation 750-1: Army materiel maintenance policies. Washington, DC: Headquarters, Department of the Army.

Fischer, G.W., Jernigan, J.H., Brandt, C.M., & Weimer, R.E. (1986). Maintenance task timelines for integrated maintenance information system - Final task report (AFHRL-TP-86-14). Wright-Patterson Air Force Base, OH: Air Force Human Resources Laboratory, Logistics and Human Factors Division.

Fredrickson, E.W., Lindquist, J.W., & Leman, J.B. (1987). An analysis of electronic aids to maintenance (EAM) for the light helicopter family (LHX) (Report submitted to ARI). Oakton, VA: Horizons Technology, Inc.

Government Accounting Office. (1987a). Army maintenance: Continuing problems in performing maintenance at the user level. (GAO/NSIAD-87-104). Washington, DC: Government Accounting Office.

Government Accounting Office. (1987b). Weapon systems: Shortfalls in automatic fault diagnostics (GAO/NSIAD-87-98). Washington, DC: Government Accounting Office.

Harris, D.W. (1985). A degradation analysis methodology for maintenance tasks (ADA 155073), Master's thesis. Alexandria, VA: Military Personnel Center.

Harz, C.R. (1981). Problems in Army vehicle maintenance: Results of a questionnaire study (RAND/R-2487-ARPA). Santa Monica, CA: RAND Corp.

ILS Lessons Learned 1985 (Customized Report). Lexington, KY: U.S. Army Materiel Readiness Support Activity.

Kane, W.D. (1984). Productivity, an organizational rather than an individual variable (ADP 003305). In Proceedings of the Symposium: Psychology in the Department of Defense, 348-352.

Kokenes, G.P. (1987). Army aircraft maintenance problems. Unpublished student report. Carlisle Barracks, PA: Army War College.

Lewellen, M.L. (1985). A simulation model for determining the effect of reliability and maintainability on maintenance manpower requirements and mission capabilities (ADA 167146). Master's thesis, Air Force Institute of Technology.

Materiel Acquisition Handbook. (1987). (AMC/TRADOC Pamphlet 70-2). Washington, DC: Department of the Army.

Moore, S.C., Wilson, E.B., Seman, T.R., Eckstrand, G.A., Lamb, T.A., Linderman, R.A., & Boyle, E. (1987). Aircraft task allocation alternatives: Exploratory analysis (AFHRL-TR-87-10). Brooks Air Force Base, TX: Air Force Systems Command.

Morphew, J.R. (1988). Special report: POMCUS/REFORGER '87: Howitzer, SP, 155MM, M109A3 (PECO/9620-88/084+008/7). Davenport, IA: Peco Enterprises, Inc.

Nauta, F. (1983). Fix-forward: A comparison of the Army's requirements and capabilities for forward support maintenance (ADA 133954). Washington, DC: Logistics Management Institute.

Nauta, F. (1985). Alleviating flight maintenance problems through maintenance training and aiding research (NTEC Technical Report MDA903-81-C-0166-1). Orlando, FL: Naval Training Equipment Center.

Orlansky, J. and String, J. (1981). The performance of maintenance techniques on the job (IDA-P-1597). Arlington, VA: Institute for Defense Analyses.

Roth, J.T. (1988a). An assessment of the ability of maintenance and logistics models to support early estimation. Butler, PA: Applied Science Associates, Inc. ARI Research Note.

Roth, J.T. and Ditzian, J.L. (1986). The human factors-training tradeoff: Pay me now or pay me (lots more) later. Maxwell AFB, AL: Proceedings of the Third Air Force Conference on Technology in Education and Training (TITE).

Shvern, U. and Stewart, J.E., II. (1988). HARDMAN II applied to the forward area air defense (FAAD) line of sight forward (heavy). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences. ARI Technical Report, in preparation.

Stewart, J.E., II and Shvern, U. (1988). HARDMAN II analysis applied to the forward area air defense (FAAD) pedestal mounted stinger (FMS). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences. ARI Technical Report, in preparation.

Vines, R., Johnston, J., Pratt, J., & Fee, K. (1980). Army aviation career management field 67 study (ADA 092063). Washington, DC: ODCSLOG, Department of Army.

Wilk, J., Narragon, E., S., & Mansir, B. (1985). Role of civilians in maintaining military equipment: Volumes I and II (ADA 168825). Bethesda, MD: Logistics Management Institute.

Campbell, W. and Kane, W.D. (1986). Why can't maintenance cure its malaise? Air Force Journal of Logistics, Summer issue, 38-41.

A model of constraints that operate on maintenance performance which either enhance or detract from its effectiveness is described in this article. The model is based on results from a large-scale attitude survey of aircraft maintenance personnel.

Chenzoff, A.P. (1985). Decision processes and information requirements for integrated diagnostics and battle damage assessment. Valencia, PA: Applied Science Associates, Inc.

This report describes the process employed by Air Force battle damage assessors as they perform their job. The process includes the decision points and the issues to be considered in task performance.

Clements, D.T. (1984). Design of an experiment to examine repair process errors of military vehicle mechanics (ADA 152229). Master's Thesis, Melbourne, FL: Florida Institute of Technology.

A model of maintenance performance and a methodology for examining maintenance process errors is presented in this paper. The model contains steps taken by a maintainer as he or she performs the task at hand. From the model, hypotheses concerning error type and frequency of error occurrence may be made and then tested in a real-world context.

Department of the Army. (1987). Army Regulation 750-1: Army materiel maintenance policies. Washington, DC: Headquarters, Department of the Army.

This regulation describes Army policies with regard to maintenance and maintenance organizations.

Drake, K.L., Goto, R.N., & Crooks, W.H. (1978). Comparative studies of organizational factors in military maintenance: Final Report (ADA 071608). Woodland Hills, CA: Perceptronics.

This report describes the results of a program to improve Army aviation maintenance operations. In the program, organizational factors influencing maintenance performance were explored. Modifications were made to some of these factors in order to determine how factor manipulations impact maintenance performance.

Drezner, S.M. and Hillestad, R.J. (1982). Logistics models: Evaluation and future trends (ADA 118808). Santa Monica, CA: RAND Corp.

This draft chapter presents a general review of types of logistics models and their deficiencies. The authors make suggestions for improvement of logistics models.

Fischer, G.W., Jernigan, J.H., Brandt, C.M., & Weimer, R.E. (1986). Maintenance task timelines for integrated maintenance information system - Final task report (AFHRL-TP-86-14). Wright-Patterson Air Force Base, OH: Air Force Human Resources Laboratory, Logistics and Human Factors Division.

This report presents a set of timelines used to determine the information requirements for an integrated maintenance information system for U.S. Air Force maintainers.

Fredrickson, E.W., Lindquist, J.W., & Leman, J.B. (1987). An analysis of electronic aids to maintenance (EAM) for the light helicopter family (LHX) (Report submitted to ARI). Oakton, VA: Horizons Technology, Inc.

Problems with electronic aids to maintenance for the LHX are discussed in this report. The primary problems result from a lack of concordance between specified RAM for the EAMs and the capabilities of the delivered aids. A model for analysis of EAMs for other systems is also presented.

Government Accounting Office (1987). Army maintenance: Continuing problems in performing maintenance at the user level (GAO/NSIAD-87-104). Washington, DC: Government Accounting Office.

This report details the shortcomings of use and maintenance activities performed by users of materiel systems and the results of these shortcomings for Army maintenance of organizations. System abuse results in an increased load on non-user levels of maintenance as does incorrect user maintenance and incomplete system status reporting by the user.

Government Accounting Office (1987). Weapons systems: Shortfalls in automatic fault diagnostics (GAO/NSIAD-87-98). Washington, DC: Government Accounting Office.

The Government Accounting Office (GAO) performed a study to determine the types of problems associated with the use of automatic fault diagnostic equipment in the performance of maintenance tasks. Several problems were identified, with the consequence of these difficulties being inefficient performance of maintenance activities.

Handbook for nondevelopment item (NDI) acquisition. (1988). Draft AMC pamphlet. Alexandria, VA: U.S. Army Materiel Command.

This draft document describes the role of MANPRINT in the acquisition of NDI. The description includes the events to which MANPRINT issues are relevant and the types of MANPRINT issues and questions that must be answered when selecting NDI.

Harris, D.W. (1985). A degradation analysis methodology for maintenance tasks (ADA 155073). Master's Thesis, Alexandria, VA: Military Personnel Center.

Harris's study describes a methodology to be employed in research on maintenance performance degradation resulting from maintainers wearing chemical warfare gear.

Harz, C.R. (1981). Problems in Army vehicle maintenance: Results of a questionnaire study (RAND/R-2487-ARPA). Santa Monica, CA: RAND Corp.

This report presents a large-scale survey study in which subject matter experts in the area of maintenance performance were asked to state their opinions as to the identification of factors negatively impacting Army vehicle maintenance performance.

Kornick, R.J., Robinson, J.E., Rogers, J.G., & Sullivan, D.L. (1981). Design engineers' concepts of skills for system operation and maintenance (NPRDC-TN-81-20). San Diego, CA: Navy Personnel Research and Development Center.

The findings of this study indicate the inability on the part of design engineers to correctly determine tasks and skills necessary for system operations and maintenance. This inability by design engineers may result in incorrect contractor-furnished estimates of KSAs and tasks.

Hutzler, W.P. and Insley, P.A. (1985). Long range enlisted manpower requirements estimation (ADA 171676). Falls Church, VA: Management Consulting & Research, Inc.

In this report, a methodology for projecting long term availability of manpower is discussed. A means for categorizing manpower requirements by aptitude during early stages of materiel system development is presented.

ILS Lessons Learned 1985 (Customized Report). Lexington, KY: U.S. Army Materiel Readiness Support Activity.

This document contains several case studies of ILS lessons learned in the areas of human factors, training, spare parts support, documentation, and safety.

Kane, W.D. (1984). Productivity, an organizational rather than an individual variable (ADP 003305). In Proceedings of the Symposium: Psychology in the Department of Defense, 348-352.

Kane's presentation from the symposium addresses the organizational and environmental aspects of the maintenance component that detract from maintainer productivity.

Kokenes, G.P. (1987). Army aircraft maintenance problems. Unpublished student report, Carlisle Barracks, PA: Army War College.

Kokenes describes negative impacts on maintenance performance that result from inaccuracies in the Manpower Allocation Chart (MAC) and Table of Organization and Equipment (TOE).

Lewellen, M.L. (1985). A simulation model for determining the effect of reliability and maintainability on maintenance manpower requirements (ADA 167146). Master's thesis, Wright-Patterson Air Force Base, OH: Air Force Institute of Technology.

Lewellen presents a maintenance simulation model to aid in the determination of answers to R&M questions. This simulation is based on a generic squadron of 24 F-15s. Mean time to repair is the independent variable and the dependent variable is mission effectiveness.

Liberati, G.L. (1983). Technology for acquiring supportable systems: Managerial overview of test and evaluation (AFHRL-TP-83-10). Brooks Air Force Base, TX: Air Systems Command.

This report contains an overview of an acquisition modeling system called the Acquisition of Supportable Acquisition Technology (ASSET). ASSET is comprised of a set of models and related databases used to assess human resources, logistic requirements, and life cycle costs for Air Force materiel systems.

Materiel acquisition handbook. (1987). (AMC/TRADOC Pamphlet 70-2). Washington, DC: Department of the Army.

This document contains the events that occur during the acquisition process performed by the U.S. Army. It also describes the formal documenation that is required by the Army acquisition process.

Moore, S.C., Wilson, E.B., Seman, T.R., Eckstrand, G.A., Lamb, T.A., Linderman, R.A., & Boyle, E. (1987). Aircraft task allocation alternatives: Exploratory analysis (AFHRL-TR-87-10). Brooks Air Force Base, TX: Air Force Systems Command.

This report presents the results of allocating different maintenance personnel mixes to tasks. The effectiveness of various allocations were tested with a logistics simulation model. The resulting simulation showed a substantial manpower savings due to restructuring of the Air Force specialties under study.

Morphew, J.R. (1988). Special Report: POMCUS/REFORGER '87: Howitzer, SP, 155MM M109A3 (PECO/9620-88/084+008/7). Davenport, IA: Peco Enterprises, Inc.

This is a report of the maintenance actions required of howitzers used in the POMCUS/REFORGER exercise of 1987. The findings suggest that systems stored for extended periods of time required more maintenance actions than systems currently deployed and maintained.

Narragon, E.A., Demchak, C.C., White, T.A., & Wilk, J.R. (1984). Re-orienting field-level maintenance (ADA 141870). Washington, DC: Logistics Management Institute.

In this report, the results of an assessment of the capability of the military departments to satisfy wartime field-level maintenance requirements of mission essential materiel systems are presented. The findings indicate that the adaptations for peacetime that have been made in maintenance strategies and organizations will, in general, not support a wartime posture.

Narragon, E.A., Neil, J.M., & Wilk, J.R. (1979). Combat and tactical vehicle maintenance in the Army (ADA 07619). Washington, DC: Logistics Management Institute.

The authors of this report present an evaluation of the effectiveness of direct support and general support vehicle maintenance units in the Army. Findings and recommendations for improvement are included in the report.

Nauta, F. (1983). Fix-forward: A comparison of the Army's requirements and capabilities for forward support maintenance (ADA 133954). Washington, DC: Logistics Management Institute.

Nauta discusses maintenance organization structure and identifies problems related to structure, maintenance strategy, and maintenance concept for selected systems.

Nauta, F. (1985). Alleviating flight maintenance problems through maintenance training and aiding research (NTEC Technical Report MDA903-81-C-0166-1). Orlando, FL: Naval Training Equipment Center.

In this report, Nauta discusses the role training and job aids can play in the alleviation of maintenance performance problems.

O'Connor, F.E., Fairall, R.L., & Birdseye, E.H. (1984). AN/TCC-39 program: A case study of manpower, personnel, and training requirements determination (ARI Research Note 84-31). Arlington, VA: Information Spectrum, Inc.

This report describes the results of an analysis of procedures used to determine MPT requirements for the AN/TCC-39 circuit switch and the accomplishment of those requirements via documentation and events detailed in the Life Cycle System Management Model used by the Army to acquire materiel systems.

Olsen, A.W. (1986). Battlefield maintenance and recovery module for the Airland Research Model (ADA 168515). Master's Thesis, Monterey, CA: Naval Postgraduate School.

This thesis presents an event model for battlefield maintenance and recovery to be incorporated into the Airland Research Model. The event model presented in this thesis focuses on a maintenance organization with two levels of repair (organizational and direct support). The output of this model is the combat value of a unit. The developed model is used to compare two maintenance strategies: 1) recover and repair, and 2) fix-forward.

Orlansky, J. and String, J. (1981). The performance of maintenance techniques on the job (IDA-P-1597). Arlington, VA: Institute for Defense Analyses.

In this report, the authors present results from an investigation of performance problems observed during maintenance actions taken at several locales. They found a wide range of performance abilities and problems, especially in the areas of troubleshooting and fault isolation.

Peterson, S.P. (1984). A maintenance support model (ADA 154440). Master's Thesis, Monterey, CA: Naval Postgraduate School.

A general structure of a sequential event model of Army maintenance support is presented in this thesis. This model is designed to be incorporated into the Corps level Airland Research Model. The level of resolution for this model is the company level maintenance team and a representative set of maintenance tasks. The model output consists of maintenance time required. The input includes outcomes of decision processes, manpower, and spare parts availability settings.

Roth, J.T. and Ditzian, J.L. (1986). The human factors-training trade-off: Pay me now or pay me (lots more) later. Maxwell Air Force Base, AL: Proceedings of the Third Air Force Conference on Technology in Education and Training (TITE).

This presentation stresses the need to seriously consider materiel system design in terms of the user and maintainer. When human factors requirements are overlooked or inadequately addressed, the result often is an increased training requirement for the system. In the long run, the increased training requirement may be less cost-effective than early consideration of human factors requirements for the system.

Shipman, C.H. (1985). An investigation of the potential manpower savings of combining Air Force specialties in aircraft maintenance (85-2390). Student report, Maxwell Air Force Base, AL: Air Command and Staff College.

The results of modeling maintenance manpower requirements when two or three aircraft specialties are combined are presented. The modeling effort uses the Logistic Composite Modeling (LCOM) simulation system. It was found that a substantial reduction in manpower requirements may occur due to the combination of specialties.

Shipton, D.L., Chenzoff, A.P., & Joyce, R.P. (1988). Effects of chemical warfare defense on airbase maintenance operations. Butler, PA: Applied Science Associates, Inc.

This report presents the findings of a study performed for the Air Force Human Resources Laboratory on the identification of performance problems associated with wearing of chemical warfare gear.

Sullivan, D. (1981). System design characteristics and user skills: A literature review (NPRDC-TN-81-9). San Diego, CA: Navy Personnel Research and Development Center.

Sullivan's report is part of a project to identify techniques for analyzing hardware and software personnel and manpower trade-offs. This report contains a review of studies focusing on design engineers' perceptions of the relationship between system design characteristics and skill requirements of system operators and maintainers.

Vines, R., Johnston, J., Pratt, J., & Fee, K. (1980). Army Aviation Career Management Field 67 Study (ADA 092063). Washington, DC: ODCSLOG, Department of the Army.

This report presents the results of an in-depth study on problems in maintenance productivity in Army aviation that are attributable to MPT policy factors.

Wilk, J., Narragon, E., & Mansir, B. (1985). Role of civilians in maintaining military equipment: Volumes I and II (ADA 168825). Bethesda, MD: Logistics Management Institute.

The authors describe the role of civilians in maintenance of materiel systems deployed by the uniformed services. The extent of civilian participation is described by locale of maintenance, level of repair, and nationality of civilian work force.

Zimmerman, Butler, R., Gray, V., Rosenberg, L., & Risser, D. (1984). Evaluation of the HARDMAN (hardware vs. manpower) comparability methodology (ARI Technical Report 646). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences.

This document contains the results from an evaluation of the capabilities of the Army's HARDMAN methodology for predicting MPT requirements for new systems during acquisition. The methodology is examined as to reasonableness, reliability, qualitative accuracy, and predictiveness.

APPENDIX A

ACRONYM LIST

ABOIP	Amended BOIP
AMC	U.S. Army Materiel Command
AMMH	Annual Maintenance Manhours
AMSAA	U.S. Army Materiel Systems Analysis Activity
AQQPRI	Amended QQPRI
AS	Acquisition Strategy
ASARC	Army Systems Acquisition Review Counsel
ATE	Automated Test Equipment
BCE	Base Cost Estimates
BIT	Built-in-Test
BITE	Built-in-Test Equipment
BDP	Battlefield Development Plan
BOIP I	Basis of Issue Plan I
CBRS	Concept Based Requirements System
CD	Combat Development
CDR	Critical Design Review
CFP	Concept Formulation Package
CMF	Career Management Field
COEA	Cost and Operational Effectiveness Analysis
CTEA	Cost and Training Effectiveness Analysis
D&O	Development and Operational
DASC	Department of the Army System Coordinator
DCARC	Defense Systems Acquisition ew Counsel
DCD	Directorate of Combat Development
DCP	Decision Coordinating Paper
DT	Development Test(ing)
DT/OT I or II	Developmental Test(ing)/Operational Test(ing)
ECA	A specific Early Comparability Analysis technique
EUTE	Early User Test and Evaluation
FAT	First Article Testing

FDTE	Force Development Test and Experimentation
FM	Field Manual
FOTE	Follow-On Operational Test and Evaluation
FSED	Full-Scale Engineering Development
FUED	First Unit Equipped Date
HFE	Human Factors Engineering
HFEA	Human Factors Engineering Analysis
HHA	Health Hazard Assessment
IEP	Independent Evaluation Plan
IER	Independent Evaluation Reports
ILS	Integrated Logistic Support
ILSMT	Integrated Logistic Support Management Team
ILSP	Integrated Logistic Support Plan
IOC	Initial Operational Capability
IOTE	Initial Operational Test and Evaluation
IPR	In-Progress Review
IPS	Integrated Program Summary
JMSNS	Justification for Major System New Start
JRMB	Joint Requirements and Management Board
JWG	Joint Working Group
KSAs	Knowledge, Skills, and Abilities
LEA	U.S. Army Logistics Evaluating Agency
LLC	Long-Lead Components
LOA	Letter of Agreement
LSA	Logistic Support Analysis
LSAR	Logistic Support Analysis Record
MAA	Mission Area Analysis
MAC	Manpower Allocation Chart
MACOM	Major Command
MADP	Mission Area Development Plans
MAMP	Mission Area Materiel Plans
MANPRINT	Manpower and Personnel Integration
MARB	Materiel Acquisiton Review Board

MARC	Manpower Requirements Criteria
MDR	Milestone Decision Review
MENS	Mission Element Need Statement
MILPERCEN	Military Personnel Center
MJWG	MANPRINT Joint Working Group
MMT	Manufacturing Methods and Technology
MOS	Military Occupational Specialty
MRSA	Materiel Readiness Support Activity
MTMC-TEA	Military Traffic Management Command-Transportation Engineering Agency
NDI	Non-Development Item
NET	New Equipment Training
ODCSLOG	Office of the Deputy Chief of Staff, Logistics
ODCSOPS	Office of the Deputy Chief of Staff, Operations and Plans
OJT	On-the-Job Training
OT	Operational Test(ing)
OTEA	Operational Test and Evaluation Agency
OTP	Outline Test Plan
OTRS	Operational Test Readiness Statement
OTRR	Operational Test Readiness Review
PEP	Productibility Engineering and Planning
PM	Program Manager
PMP	Program or Project Management Plan
PPBES	Planning Phase of Planning, Programming, and Budget Execution System
QQPRI	Qualitative and Quantitative Personnel Requirement Information
R&M	Reliability and Maintainability
RAM	Reliability, Availability, and Maintainability
RFP	Request for Proposal
ROC	Required Operational Capability
RRR	RAM Rationale Report
SCP	System Concept Paper
SME	Subject Matter Expert
SMMP	System MANPRINT Management Plan

SOW	Statement of Work
SSA	System Safety Assessment
SSG	Special Study Group
SSP	System Support Package
STF	Special Task Force
STRAP	System Training Plan
TRADOC	U.S. Army Training and Doctrine Command
TDNS	Training Device Need Statement
TDP	Technical Data Package or Test Design Plan
TDR	Training Device Requirement
TEA	Training Effectiveness Analysis
TECOM	Test and Evaluation Command
TEMP	Test and Evaluation Plan
TM	Training Manual
TMDE	Test, Measurement, and Diagnostic Equipment
TOA	Trade-off Analysis
TOE	Table of Organization and Equipment
TP	Training Plan
TQQPRI	Tentative Qualitative and Quantitative Personnel Requirement Information
TRADOC/CD	U.S. Army Training and Doctrine Command/ Combat Development
TRASSO	TRADOC Systems Staff Office
TSM	TRADOC System Manager
TSP	Test Support Plan
TTHS	Trainees, Transients, Holdees, and Students
TTSP	Training Test Support Plan

APPENDIX B

GLOSSARY

Accessibility Design	Design of a system such that components to be maintained are easily accessible
Achieved RAM	System reliability, availability, and maintainability that is actually achieved after system deployment
Acquisition Strategy	The strategy by which the Army acquires a system
Actual Manpower	The number of personnel with a required skill background actually available to perform a maintenance task
Actual Personnel KSAs	The knowledge, skills, and abilities of personnel actually available to perform a maintenance task
Allocation of Tasks	Task-by-task allocation of maintenance tasks to specific levels of repair
Aptitudes	Untrained capabilities demonstrated by an individual
Automatic Fault Diagnostics	Existence of TMDE, BIT, or BITE to diagnose material system faults
Automatic Fault Diagnostics Use	Use of automatic fault diagnostic equipment by maintainers

Basis of Issue Plan	Planning document used in Army system acquisition that lists certain TOE (level), Table of Distribution and Allowances, Common Tables of Allowances, Joint Tables of Allowances, and Additive Operational Products in which a new item will be placed, the number of items to be included in each organizational element, and other equipment and personnel changes needed because of the new item
BIT or BITE Capabilities	Diagnostic capabilities of built-in tests or built-in test equipment
Crew Preventive Maintenance	Maintenance performed by system operators or crew necessary to prevent need for repair actions
Diagnosis	The act of determining causative factors producing system malfunction(s) based on the observation of symptoms
Distractors	Duties and personal activities that consume time that would have been used for actual maintenance tasks
Documentation	Documents or references supplied to support system maintenance
Driver Factors	Factors whose impact propagates across a maintenance system
Eaches	Individual units or systems to be deployed
Entry Level Characteristics	Knowledge, skill, abilities, and numbers of untrained personnel
Experience	Experience in maintenance activities with the same or a related materiel system

Extended Storage of Equipment	Storage of unused materiel systems for long periods of time, often without inspection or maintenance until removal
Facilities	Characteristics of the physical environment that affect job performance (e.g., noise, light, clothing)
Failure Modes	Ways in which the materiel system can fail and require maintenance actions
Failure Modes Analysis	Analysis of ways in which the materiel system can fail and require maintenance actions
Fault Isolation Tasks	Maintenance tasks related to discovering where a problem lies. These tasks may depend on general troubleshooting KSAs
Force Structure	Overall structure of an organization (e.g., Army, Career Management Field)
History	Maintenance and logistics experiences with related and predecessor materiel systems
Human Factors Engineering	Design of the materiel system for ease of operation and maintenance
Knowledge, Skills, and Ability (KSA)	The KSA requirements associated with maintenance tasks to be performed on a system
Levels of Repair or Levels of Maintenance	Structure of the system support structure (e.g., organizational, direct, general, depot)
Logistic Support Analysis (LSA)	The determination of all support equipment and supplies needed to support the system in the field

Maintainability Design	Design of the materiel system for ease of maintenance (e.g., BIT or BITE, access, clarity of markings, testability)
Maintenance Burden	The elements that must be provided to support the maintenance of a materiel system
Maintenance Concept	The approach to materiel system maintenance and the levels of maintenance necessary to perform tasks
Maintenance Levels	The particular organizational levels at which maintenance is performed
Maintenance Location	Site where maintenance is performed (e.g., battle site, garrison, mobile unit, shop)
Maintenance Perspective	Type of scenario in which maintenance will occur
Maintenance Tasks	The actual tasks that comprise the activity of maintenance
Maintenance Strategy	Overall approach to materiel system maintenance (e.g., fix-forward, recover and repair)
Management and Supervision	Whether maintenance managers and supervisors motivate and guide their subordinates, and plan maintenance activities
Manpower	Allocation of personnel to a particular task
Manpower Availability	The numbers and types of personnel available to fill required maintenance positions
Manpower Pool Characteristics	Numbers of untrained personnel available and their current KSA's
Manpower Requirements	Number of personnel required for maintenance activities

Migration into Career Management Field (CMF)	Process whereby personnel transfer into a particular CMF from other CMFs
Military Occupational Specialty (MOS)	Job classification number assigned to personnel who are to perform a specified set of tasks
Military Occupational Specialty (MOS) Data	Types of MOSs to be used for maintenance and their constraints on system-specific training
New Ideas	Training, logistical, and maintenance concepts that differ from previous approaches
Non-Developmental Item	A materiel system purchased off-the-shelf, usually accompanied by nonmilitary technical documentation
Number of Personnel to be Trained	Total number of trainees to enter the training system to be maintainers and system support personnel
On-Demand Maintenance	Maintenance performed when required by a failure or imminent failure
On-The-Job Training (OJT)	On-the-job training for the maintenance task
Operational Tempo (OPTEMPO)	The planned usage rate of the materiel system
Organizational and Operational (O&O) Concept	Drives some of the characteristics of the maintenance function and may also establish goals and impose constraints that influence characteristics of the maintenance subsystem
Organizational and Operational (O&O) Constraints	Limits on allowable maintenance strategies, demands on resources, and operational capabilities

Organizational and Operational (O&O) Plan	The program initiation document in the materiel acquisition process; prepared prior to the ROC to support acquisition of all new materiel systems
Organizational Concepts	Plan of which units will perform which types of maintenance
Organizational Structure	The structure of the units that will use the materiel systems and the organizations that will provide maintenance for these systems above the unit level
Parts Availability	Whether parts are available using official procurement methods
Parts Commonality	Whether required part are the same as those used in other systems or sub-systems
Personnel	People needed for a level of repair
Personnel Knowledge, Skills, and Ability (KSA)	KSAs of trained personnel; these reflect all training and personnel inputs
Personnel Requirements	Number of trained personnel needed and their MOSs and skill levels
Personnel to be Trained	Untrained personnel selected from the manpower pool
Planned Manpower	The planned allocation of personnel quantity to a particular task
Planned Reliability, Availability, and Maintenance (RAM)	Any specific restrictions or aids that apply to the maintenance of a system (e.g., length of time required for maintenance, expected frequency of maintenance)
POL, Ammo, etc.	Expendable or consumable items required for support of the materiel system

Preventive Maintenance	Scheduled maintenance actions taken to avert later need for more extensive repair
Promotion Flow	The movement rate of personnel up the military career ladder
Provisioning	Part of the Production Base Support Program that provides for initial production facilities, modernization, expansions, and support of production facilities
Publications	Maintenance documents to support task performance
Publication Use	Whether the maintainer knows how and actually uses technical publications in task performance
Quantitative and Qualitative Personnel Requirements Information (QQPRI)	A compilation of specified organizational, doctrinal, training, and personnel information developed by the materiel developer and combat developer for new or modified materiel items
Reliability, Availability, and Maintenance (RAM) Factors	Factors that affect the frequency and process of maintenance
Required Operational Capabilities (ROC)	A document which concisely states the minimum essential operational, technical, logistical, and cost information necessary to initiate full scale development or procurement of a materiel system

Service and Repair Tasks	Highly procedural tasks associated with regular service of a materiel system, or with the repair of that system once a fault has been isolated
Skill Level	Level of maintenance KSAs corresponding to the last two digits of a five-digit MOS
Skill Needs	The skills needed by personnel to perform a specific maintenance task
Spare-Parts Availability	Whether required spare parts are actually available at the repair organization
Spare Parts and Expendables Provisioning	Amount of spare parts planned for in logistical plan
Spare Parts	Replacement parts retained for future use
Summative Manpower Requirements	The total number of personnel required to field a system
System	A piece of equipment, apparatus, or supplies, such as tanks and aircraft, which support a military force
System Components	Breakdown of the materiel system into maintainable subunits down to the LRU level
System Design	The description of the hardware and software of the materiel system
System Maintenance Characteristics	The characteristics of the materiel system from a maintenance point of view, including maintainability design, criticality of maintenance actions, etc.
System Maintenance Profile	The particular organizational level at which each maintenance task is performed

System Status Reporting	Operators and maintainers documentation of events leading to a maintenance action
Table of Organization and Equipment (TOE)	A description of an Army unit including personnel and equipment authorized under unit organization
Task	A maintenance function that a person, unit, or thing is expected to perform
Task Allocation Strategy	The plan for assigning each type of maintenance task to a maintenance level
Task Performance Requirements (TPR)	Numbers of different types of personnel needed to perform a given maintenance task
Tenure	Amount of time a maintainer of a materiel system or related system
Test, Measurement, and Diagnostic Equipment (TMDE)	Any system or device used to evaluate the operational condition of a system or equipment to identify or isolate any actual or potential malfunction
Test, Measurement, and Diagnostic Equipment (TMDE) Capabilities	The troubleshooting capabilities of a piece of TMDE
Test, Measurement, and Diagnostic Equipment (TMDE) Use	The use or lack of use of TMDE by maintainers
Tool Control	Availability of authorized tools when needed

Trainees, Transients, Holdees, and Students (TTHS) Factors Data	Factors that are applied when attempting to estimate the total number of personnel in the personnel pipeline for a given MOS
Training	Training provided via institutions, OJT, and other means
Training Concepts	Plans for training approaches, devices, and content
Training Motivation	The desire on the part of personnel to receive OJT or take part in other forms of supplementary training and the desire of supervisors to provide training
Training Requirements	Objectives to be trained by the training subsystem
Training Subsystem	All training-related aspects of the materiel system, including training methodologies, trainees, instructors, objectives, etc.
Use Rates	Rate of use of the materiel system

APPENDIX C

MAINTENANCE PROCESS MODEL

This model represents the action and decision flows with respect to corrective or on-condition maintenance for a system. The model is intended to be independent of differences in maintenance concept and strategy found with different types of systems (e.g., helicopters and tracked vehicles). It is also intended to be generic with respect to levels of maintenance (e.g., unit, direct support, general support, depot) within a maintenance system. The value of the generic nature of this model is that this attribute provides the broadest possible base for examining the factors and variables that influence the maintenance function. It allows examination of maintenance without considering the details of specific maintenance strategies or concepts, which could obscure the impact of factors that act in all maintenance situations. In other words, the nature of the model allows examining the maintenance "forest" without paying attention to details of the "trees" that make up the "forest."

Model Genesis

This model is derived from several existing maintenance process models and discussions of the Army maintenance process, including those developed by Chenzoff (1985), Fischer, Jernigan, Brandt, and Weimer (1986), and Naura (1983, 1985). These models and descriptions were examined, and an attempt was made to synthesize the appropriate and relevant features of each into a single descriptive and explanatory model of a generic maintenance function. After the model was logically developed through several iterations, a Subject Matter Expert (SME) familiar with maintenance and maintenance processes examined the model in two iterations. Several corrections and extensions were suggested by the SME, and were added to the model.

Model Discussion

The model is graphically represented in Figure C-1 (foldout at the back of this volume). In this Figure, processes are represented by rectangular shapes. Within a shape, the specific process represented by the shape is described. Diamond shapes represent decisions that are made within the maintenance process flow, or alternate outcomes with respect to processes. Each decision has multiple (usually two) outcomes, which lead to different successor actions or decisions. Ultimate outcomes with respect to the maintenance process are repre-

sented by oval-shaped terminal nodes in the model. These represent the disposition of a maintenance action given the total set of processes and decisions that lead to each terminal. Flow from one node to another in the model is represented by conventional directed graph or flow lines.

At several points in the graphic depiction of the model, "Potential Impacts," or factors that are suspected to influence the performance of the maintenance process at a particular node, are listed in Figure C-1. These are discussed in the following text. The likely impacts of each impact factor are discussed when the factor is first encountered in the model discussion. Later occurrences of an impact factor are simply referenced, unless there is some unique aspect to the factor's impact at some particular node. It should be understood that the characteristics of the design of a given system are considered to be an impact factor at all points in the maintenance process. It is system design, and features included in the design to promote testability and maintainability, that is the ultimate driver of maintenance requirements. Other factors act to influence how well the maintenance requirements are fulfilled, in the operation of the maintenance function for a system.

Before discussing the details of the process model, one caution should be made clear. This model was necessarily derived from consideration of processes that occur when a fault is found or suspected in a system. Thus, it is derivatively a "corrective maintenance" model. However, preventive or routine periodic maintenance is implicitly included in the model. This inclusion is made by specifying inspection and periodic maintenance activities as the first process in the model's flow.

The remainder of this subsection explains the model, node by node, including decision factors. With respect to decision nodes, the horizontal branch (with respect to the depiction in Figure C-1) is always discussed first, followed by the vertical branch.

Fault Occurrence (top node, left portion of Figure)

The first model node is the occurrence of a fault in the system, which is actually or hypothetically detectable by human maintainers with or without the assistance of Test, Measurement, and Diagnostic Equipment (TMDE). Faults include indigenous faults (from wear and tear or breakdown of the system) and exogenous faults (from battle damage or other external trauma such as bird strikes to aircraft).

Symptom Discovery (top half, left portion of Figure)

Practically all systems are subject to inspection and checkout before, during, and after missions or other assigned functional uses of the system. Most systems also undergo some type of preventive maintenance or periodic inspection. It is during these activities that

opportunities for the initial discovery or perception of faults occur. This model element includes the inspection or preventive maintenance activities, and the decision as to whether existing faults are perceived by the crewmembers or the maintainer. If fault indications or damage go unnoticed, or are ignored, undiscovered faults remain in a system (right-hand decision branch). When this is the case, the system is normally returned to service availability as though it were not faulted. Some discussion of impacts of this state of affairs are discussed below with respect to the impact factors at this point in the process model. When a fault indication is perceived (and attention is paid to it), the next step is to confirm the fault (downward decision branch). This branch would also be followed in the case of a false alarm (a decision that a fault exists when, in fact, there is no fault).

Factors which influence the maintenance function at this juncture include the following.

1. Built-in Test or Built-in Test Equipment (BIT or BITE). Considerable reliance is placed on BIT or BITE for fault identification and diagnosis in many complex systems. These features of system design are utilized to detect and signal fault conditions in some manner, either continuously during system operation, or on demand from a system crewmember or a maintainer.

   There is a wide variety in the ability of these features to detect and localize faults, and in the reliability of fault detection and localization by the features. This variety occurs both within systems of a given type (because of different configurations of software or diagnostic hardware) and across system types. False (positive or negative) or ambiguous fault indications are common when BIT or BITE features of systems are used.

   In some cases, fault indications are presented in cryptic and hard-to-remember codes, which increases the memory load on maintainers, or requires including the codes in technical documentation which, itself, is often difficult to locate or use. When BIT or BITE indications are ambiguous, it is necessary to rely on manual fault detection and localization methods, which increases skill requirements for the maintainer workforce and may also require additional manpower and time to perform maintenance.

   BIT or BITE also itself requires maintenance, which increases required maintainer workforce skills and can lead to system downtime for "fixing the diagnostics." And, many BIT or BITE features require more advanced skills for effectively using BIT or BITE capabilities (see Nauta, 1985; Shvern and Stewart, 1988; and Stewart and Shvern, 1988). This has a tendency to contribute to the need for

more highly trained and skilled maintainers than is the case without BIT or BITE.

2. Test, Measurement, and Diagnostic Equipment (TMDE). This factor refers to TMDE which is not included in the BIT or BITE capabilities of the system (i.e., separate test equipment). With many systems, TMDE is provided to facilitate test and inspection of system functions. Both special-purpose (e.g., Specialized Test Equipment for Internal Combustion Engines [STE-ICE]) and general purpose (e.g., oscilloscopes, multimeters) may be used with a given system. Well-conceived and well-designed TMDE can simplify maintenance in the same conceptual manner as BIT or BITE. However, many items of TMDE require special skills for their operation. This tends to increase the overall skill demands on the maintainer workforce (see Nauta, 1985).

   Also, special-purpose TMDE often incorporates many of the functional shortcomings of BIT or BITE in practice, both in the ability to detect and confirm faults and in fault localization capability. This compounds the maintenance burden, since manual methods must be used to back up TMDE when it is not reliable. Also, many items of TMDE are very time-consuming to set up and operate (in addition to their increased skill demands), which exacerbates the demand on a typically already heavily-loaded maintenance function.

3. Maintenance Manpower. This factor refers to the absolute number of person-hours available to perform direct maintenance activities. When maintenance demands are established during the system acquisition process, they are invariably based on a wartime, European-theater scenario, by doctrine.

   Many assumptions about organizational structures and Tables of Organization and Equipment (TOE), spare parts availability, task requirements, personnel availability ratios, and numerous other factors are used in maintenance manpower requirements determination. Given a peacetime, garrison-and-exercise area or -range scenario, these predictions almost universally underestimate maintenance manpower requirements. This is not meant to imply that peacetime maintenance is more intense, or occurs at a more rapid tempo, than wartime maintenance. Rather, it reflects the peacetime practice of under-filling TOE manpower authorizations, and plans for wartime strength augmentation by Reserve Component and National Guard personnel. This is particularly the case in regard to intermediate-level maintenance. Other contributors to this difference include dilution of available maintenance manpower resources by non-maintenance-oriented activities and duties, lack of urgency in demand for system maintenance, and a totally different pattern of motivation to perform.

While the maintenance function is afforded some priority during peacetime, it is commonly also viewed as a source of manpower to perform functions other than maintenance. This dilutes the available manpower to perform direct maintenance. While this factor does not contribute directly to the system maintenance burden, it impacts the ability of the maintenance function to bear the burden imposed by other factors.

4. Crew Maintenance Skills. It is common for the users of a system (crewmembers or operators of other sorts) to perform the daily or pre- and post-operational checkout and test, and much of the routine servicing, of a system. This means that the crewmembers are the individuals who have the greatest opportunity and the most direct responsibility to detect system faults, thus placing a system into the maintenance process.

   If crew skills with respect to fault detection are not developed, or if crewmembers fail to report faults discovered in their systems (common with wheeled vehicle operators), then faults can remain unknown to the maintenance system. Also, failure to perform routine servicing can seriously increase corrective maintenance needs. These generally will have the effect of causing further deterioration in system condition, propagated faults (something breaks because something else is already broken), or both.

   This can increase the maintenance burden by causing manpower-demanding tasks to have to be performed with higher than planned frequency. An example is the need to change a tank powerpack because of failure to service the powerpack properly, or ignoring a fault indication such as a warning light indicating that metal chips are present in lubricants within the engine.

5. Technical Documentation. Technical manuals (TMs) are the basic information repository for both maintenance instructions and information that helps maintainers to detect and isolate faults. The information in TMs is sometimes poorly organized, incomplete, inaccurate, or out-of-date with respect to a particular model of a system. This can obviously impact all phases of the maintenance process. Climate impacts include performance of the wrong task, performing the right task in the wrong way, using the wrong parts for a repair, or mis-diagnosing a fault. Each of these outcomes leads to an increase in the overall maintenance burden.

   Also, technical documentation is often not available or not complete at a given worksite. This impacts available personnel time for direct maintenance, since manuals have

to be located and brought to the worksite. It is not uncommon for a maintainer to have to go through several iterations of search-for-the-right-information-in-the-manuals for a particular task. This includes leaving the worksite, locating the volume of documentation which supposedly has the needed information, determining whether the information is in fact present, returning to the worksite, and attempting to use the information in task performance.

In many cases, information needed for a task (particularly fault isolation) is distributed over several volumes of information which are physically located at different places in the maintenance organization. It is not uncommon for predicted maintenance task times to be increased by a factor of two or three or even more by the hunt for the right documentation. This clearly impacts the available manpower to perform direct maintenance.

6. Procedures. For any given system, there are likely to be several alternate procedures for detecting and isolating a given fault, or performing a particular maintenance task. While most service and repair tasks are at least nominally guided by specific procedures in technical documentation, fault isolation and troubleshooting tasks are not always highly proceduralized. In particular, a specific fault indication (perhaps an "idiot light", or even BIT or BITE or TMDE readouts) can potentially indicate a fault in any one or more of a large number of components (i.e., there is a large "ambiguity group" associated with a fault indication).

   In some cases, attempts have been made to proceduralize the fault isolation process for a system, or for one or more component subsystems. One of the motivators for doing so is the hypothetical ability to use lesser-skilled personnel for the fault isolation task, reducing overall skill demands in the maintainer workforce. In such cases, assumptions with respect to maintenance manpower and, therefore, TOE personnel authorizations, appear to be based on a reliance on proceduralized troubleshooting to be successful.

   However, there are almost always some faults or symptom patterns that are not covered by the fault isolation procedures. When this occurs, higher-skilled personnel must be used to successfully troubleshoot the fault(s). This clearly increases the overall maintenance burden, since the lower-skilled personnel may be idled while higher-skilled personnel perform fault isolation (see Shvern and Stewart, 1988 and Stewart and Shvern, 1988).

7. Training. The Army's philosophy with respect to maintenance training is to qualify the maintainer to a helper level in the institution, relying on On-the-Job Training (OJT) in the unit to develop higher levels of skill. This reliance on unit OJT for skill development is not typically realized in practice.

   In the unit, the supervisory personnel responsible for conducting OJT frequently do not have the time, motivation, or skills (see Nauta, 1985) to perform their training function effectively. This leaves the lower-skilled helper level personnel to learn by trial and error, when they are allowed to perform tasks at all. In many cases, the skills of lower-level personnel are sufficiently distrusted by supervisors (possibly due to the relatively limited level of skill that can be imparted by the institution) that the lower-level people seldom or never are assigned to a task independently. This, coupled with the frequently high demand for direct task performance on the part of higher-skilled people, means that the actual maintenance manpower base available is considerably less than that suggested by a unit's TOE.

Fault Confirmation (lower half, left portion of Figure)

After a fault indication is perceived, the next step of the process is to replicate the fault indication, to try to eliminate false alarms. This is normally done by examining system displays, interrogating BIT or BITE, or occasionally using stand-alone TMDE to validate a fault indication. This part of the maintenance process can be entered from three points: fault detection (at the current level of maintenance), from a lower level of the maintenance process from which a system has been "pushed back," and from a failure of corrective action to eliminate fault symptoms. If the fault is not confirmed by whatever means are used, a "cannot duplicate" condition exists, and the system is returned to service, possibly with a fault still present (right-hand decision branch). If the fault is confirmed, the next step is isolation of the fault to repairable components (downward branch, leading to the center section of the Figure).

Several factors have potential impacts on the success of the fault confirmation function. They are: (1) BIT or BITE; (2) TMDE; (3) maintenance manpower; (4) technical documentation; (5) procedures; and (6) training.

Fault Isolation (top half of center section of Figure)

After fault confirmation or replication of symptoms from the original problem, the next step is to isolate the fault to the malfunctioning or damaged components, so that the components can be repaired or replaced (as appropriate to the level of maintenance).

This process is affected by several factors: (1) BIT or BITE; (2) TMDE; (3) maintenance manpower; (4) technical documentation; (5) procedures; and (6) training.

If the fault is not isolated to appropriate repairable system components at the current level of maintenance (right-hand decision path, left-hand decision block), then a decision is required as to whether additional fault isolation is appropriate at this level of maintenance. The decision is commonly based on resource availability (i.e., manpower). If manpower is not available at the current level of maintenance (right-hand decision path, center decision block), then help, in the form of a maintenance contact team, may be available from a higher level of maintenance. If resources are available, fault isolation continues at the current level of maintenance (upward decision path, center decision block). Potential impact factors on this decision are maintenance manpower and workload. Workload is defined here as the number of maintenance tasks currently in progress plus the backlog of maintenance tasks to be performed at this level of maintenance.

When contact team assistance is not available (right-hand decision path, rightmost decision block), then the fault isolation and repair is pushed back to a higher level of maintenance, and the system is evacuated to the appropriate maintenance collection point. When a contact team is available (upward decision path, rightmost decision block), then maintenance is assigned to the contact team. After the contact team has performed the appropriate fault isolation and repair, the system will be checked out (after reinstallation in a higher level assembly or system) at the current level of maintenance before it is restored to service availability. Impact factors on this decision are the maintenance manpower and workload of the contact team.

If fault isolation is effective, the next part of the maintenance process is to decide whether resources are available at the current level of maintenance to perform the needed repairs.

Repair Level Decisions (Bottom half of center portion of Figure)

The first decision here is whether the repair required is within the doctrinally-approved capability of this level of maintenance. If the repair is not within the approved capability of this level (right-hand decision path), then the maintenance action is automatically pushed back to the next higher level of maintenance. Factors that impact this decision are the maintenance concept for the system (what levels of maintenance exist for a system and their identity) and the level of repair analysis for maintenance---which repairs can be performed at each level of maintenance. These factors are established during planning for the new system, and as part of Logistical Support Analysis (LSA) activities for a new system.

If a required repair is within the approved capability of this level of maintenance (downward decision path), the next decision is

whether personnel resources are available to perform the repair. This decision is taken with respect to a delay time established by doctrine. The delay time specifies the amount of time that a system can spend awaiting maintenance at a given level of maintenance before the specific system must be pushed back (rightward decision path) to the next higher level of maintenance. This time is commonly established at twelve hours for Army maintenance organizations under combat doctrine. Factors influencing this decision are maintenance manpower, workload, and doctrine (the established delay time for this system at this level of maintenance).

If personnel resources are available (downward decision path), the next decision is whether spare parts are available within the delay time to effect repairs. If spare parts will not be available to support repair within the delay time, then an automatic pushback of maintenance to the next highest level of maintenance takes place (rightward decision path). Factors influencing this decision are spare parts availability (as determined by the applicable Prescribed Load List [PLL] or Additional Spares List [ASL] for the level of maintenance involved, and other ongoing and prior repair activities) and doctrine (establishing the allowable delay time).

If it is determined that spare parts are available for the required repair, the action is assigned and performed (downward decision path, leading to the rightmost portion of Figure C-1).

If it is determined that spare parts are not available from supply stockage or other normal sources, controlled substitution from other like-type systems (right-hand decision path) may be considered. In some (presently rather rare) cases, controlled substitution from a different type system having common parts with a target system may be considered. If controlled substitution is not authorized, then a pushback to the next highest maintenance level takes place (upward decision path).

If controlled substitution is authorized, then the controlled substitution action is performed (right-hand decision path), followed by the appropriate repair action and checkout. Factors impacting the controlled substitution decision include basic policy (whether controlled substitution is permitted at all, and to what extent), and the availability of other systems from which to obtain parts. It should be noted that controlled substitution multiplies overall repair times by a large factor, with a consequent increase in maintenance manpower demands. When removal of parts from another system and later repair of the "donor" system are considered, as well as associated decision and delay times, controlled substitution may require five times or more the manpower resources of a normal repair action when spare parts are available (D.L. Shipton, personal communication, 31 March 1988).

In cases where damaged systems (to be discarded rather than repaired) are available, some spare parts may be removed from such systems and used in the repair of other systems. This process is referred to in official documentation (AR 750-1) as cannibalization.

Cannibalization will tend to have an inflating effect on maintenance manpower requirements similar to that associated with controlled substitution, but to a lesser extent, since systems that are cannibalized are not later repaired.

Maintenance Action and Checkout (top half, right portion of Figure)

The next activity in the maintenance process is performing the actual repair action and a subsequent checkout to ensure that the fault has in fact been corrected. Factors that influence the actual repair process include: (1) maintenance manpower; (2) the availability of appropriate tools needed to perform the repair; (3) procedures; (4) technical documentation; (5) TMDE; and (6) training.

Checkout is performed both on systems repaired by the maintenance organization at the current level of maintenance, as well as on systems repaired by contact teams from higher levels of maintenance. Checkout occurs on repaired components or systems received from higher levels of maintenance only at the time the repaired items are placed in service.

If the post-maintenance checkout indicates that the repair process was not successful (there are still malfunction indications; right-hand decision path), then the symptoms are evaluated to see whether the symptoms are the same as those of the original problem, or different symptoms are present (probably indicating either a parallel fault or a fault induced by the maintenance process). If the symptoms are the same as the original symptoms (upward-hand decision path), the fault isolation activity is re-entered. If the symptom pattern is different from the original (right-hand decision path), an attempt is made to replicate the symptom pattern.

Post-repair Activities (bottom half, right portion of Figure)

After repair and checkout are complete, inspection by a Technical Inspector may be required (downward decision path from checkout). If inspection is not required, then the system is returned directly to service (right-hand decision path). If inspection is required (downward decision path), the availability of a Technical Inspector to conduct the inspection is determined. If an inspector is not available (right-hand decision path), then the system is queued to await inspector availability.

If an inspector is available, then the inspection is performed. Inspection performance is influenced by maintenance manpower, technical documentation, training, TMDE, and procedures. If the system does not pass inspection (right-hand decision path), the failure to pass is evaluated as to whether its source is due to system functionality (upward decision path) or workmanship (right-hand decision path). Sometimes a workmanship evaluation is not made.

If functionality is the cause of the failure to pass, the system re-enters the maintenance process with an attempt to replicate the symptoms that caused the failure in inspection. If the cause of the failure is workmanship, the repair decision process is entered.

If the system passes inspection, then it can be immediately returned to service (upward decision path from inspection decision).